

**SCIENCE
IN MODERN LIFE**

PREFACE

That the nineteenth century, especially its second half, witnessed a Scientific Renaissance of the most astonishing kind, the results of which have profoundly affected modern civilization, is a fact of such deep significance that it cannot be too often repeated. The foundations of Science were indeed laid long before this epoch, and one branch at least—Astronomy—had already attained a prominent position. But such subjects as Geology, Chemistry, and Physics, together with the several departments of Biology, were all in a more or less rudimentary condition at the close of the eighteenth century. Many causes combined have led to the rapid growth of scientific knowledge, but probably the most potent factor is to be found in the theory of Evolution, in the form advanced by Charles Darwin and Alfred Russel Wallace just fifty years ago, which revolutionized our ideas of life and living beings, much as Lyell's geological work, based on that of Hutton, had previously superseded the views then current regarding the relations between the past and present physical features of the globe. Furthermore, evolutionary ideas have now permeated all regions of human thought and research, and are daily applied to such diverse subjects as philology, literature, history, political economy, sociology, and theology, always, be it remarked, with the most fruitful results.

The material outcome of a century's scientific advance is remarkable both in quality and quantity. To get back from present-day conditions to those of the early nineteenth century by elimination of scientific applications, could this be done all of a sudden, would deprive us of innumerable things which most of us now regard as matters of course. Away would go all means of

rapid transit and communication, and manufactures would cease their activity. Even the ancient industry of Agriculture would be sadly crippled. Those undergoing medical treatment would have their chance of cure considerably diminished, especially in surgical cases, for the absence of aseptic precautions and anaesthetics would prevent anything being done for ailments which now lead to comparatively little mortality, *e.g.* appendicitis and other lesions involving abdominal section. The streets would be but dimly lighted, photographs and countless other things would vanish from the shops, most of the colours that minister to the sense of beauty would disappear from textiles and the like, while the army and navy would scarcely know themselves. Muzzle-loaders for Lee-Enfields, smooth-bores for rifled cannons, *Victories* for *Dreadnoughts*!

The object of this work is to give a connected and, as far as possible, non-technical sketch of the present position and outlook of natural science, with especial reference to its influence on modern life. It is believed that many will welcome an attempt to present the matter with a certain amount of "perspective". To the lay reader most will be either new, or placed in a new light. The specialist is asked to forgive the—for him—common-places in his own subject, and to turn to sections with which he is less familiar.

The work is in no sense a textbook, nor is it intended as such, and in some cases a little elementary knowledge is assumed, though the manner of treatment of most subjects will render even this modicum of previous knowledge not an essential for intelligent comprehension of the subject.

The scheme adopted is an evolutionary one, and renders possible a fairly logical order of subjects. We naturally begin with ASTRONOMY, which deals with the globe as an infinitesimal speck in an evolving universe, the careful study of which throws some light on its mode of origin. The story of our earth is then continued in the section on GEOLOGY, which explains the past by the present, and traces in some detail the long series of gradual changes which have resulted in the existing distribution of land and water. Some matters of practical importance, such as the origin of coal and rock-salt, also receive attention.

form the raw materials of very many modern industries are then dealt with under **CHEMISTRY**. Here we find a presentation of the gradual growth of chemical theories, as rendered possible by increasing knowledge of facts. Where relevant, details are given of the more important practical applications. Coal-tar products, the winning of metals from their ores, incandescent mantles, and explosives are among the selected topics.

Next follows a section on **PHYSICS**, treating of the forces at man's disposal, and their applications. The leading facts and theories of Sound, Light, Heat, and Electricity are all taken into account, and many industrial matters are fully discussed. It will suffice to mention telegraphy, telephony, and photography.

The complex problems presented by life and living matter occupy a considerable space, under several headings. Some general principles are first considered in a short section on **GENERAL BIOLOGY**, which is followed by a longer one on **BOTANY**. This deals with modern aspects of the subject, such as the complex relations between plants and their surroundings (oecology), and the broad outlines of plant evolution (phylogeny). Extinct forms are considered as well as those now existing, for without them many problems regarding the origin of vegetable groups would be hopelessly insoluble. An outline of plant distribution is appended. A section on **ZOOLOGY**, treating animals in similar fashion, succeeds.

Under the headings of Botany and Zoology enough of the ancient life-history of the earth is given to supply an elementary idea of the succession of forms in sea and on land which existed during the series of conditions described under Geology.

Some of the applications of biology are alluded to in both the botanical and zoological sections, but certain matters are reserved for further treatment.

A distinct section, for instance, is given to **FISHERIES**, in which active scientific work is going on in the United States, Germany, and Norway, while something is being done in Britain, though government support is at present meagre.

AGRICULTURE, again, which is largely the application of natural science to the raising of crops and stock, occupies a distinct section. This takes the form of a historical survey, setting forth the leading

factors of progress at different epochs. The importance of scientific research in relation to agriculture is fully appreciated by the United States, Germany, Denmark, and Holland; Britain, once more, is far behind, though there are signs of a somewhat tardy awakening to the national importance of original investigations having a bearing on agriculture.

A short section on PHILOSOPHICAL BIOLOGY helps to round off the botanical and zoological sketches, by dealing with the evolution theory and its corollaries. Its bearings upon such departments of study as sociology are also indicated.

Man in health and disease is considered in the section on PHYSIOLOGY AND MEDICINE, which lays stress on the powerful weapons for the prevention or cure of maladies which modern science has placed at the disposal of surgery and medicine. In this direction Britain can so far challenge comparison with other countries.

The succeeding section on ANTHROPOLOGY deals with the human species as contrasted with the individual man. The evolution of civilization in various directions is outlined, and some account is given of the races of mankind.

It has been deemed appropriate to conclude with ENGINEERING, including descriptions of recent advances which applications of Chemistry and Physics have rendered possible. Some of these have already found a place in the sections on those subjects, but complex mechanical devices fall more naturally to Engineering proper. A prominent place has been assigned to the appliances by which various modes of transit have been perfected. The importance of these to the advance of civilization can scarcely be overestimated, and, associated with such rapid means of communication as wireless telegraphy, they may render possible the continuance of a world-empire like our own.

But as, at present, and for an indefinite period, the fate of nations is liable to be determined by force of arms, the concluding pages are devoted to the mechanical appliances which now render war by land or sea so tremendous a business.

J. R. A. D.

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ASTRONOMY

BY

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INTRODUCTORY

OUR OUTLOOK ON THE UNIVERSE

FIRST IMPRESSIONS.—The first rough impression that our senses convey to us regarding our position in space is that we are situated on an indefinitely large, nearly plane, and immovable solid foundation, which we call the Earth. In the sky above us float various luminous objects, differing vastly among themselves in brightness, and seemingly all of a nature entirely unlike that of the Earth. One in particular, the Sun, stands out from the rest as the ruler of the day and the year. While he is above the horizon, the lesser lights disappear in his brightness, while his heat is obviously necessary for the existence of animal and vegetable life on the Earth. The polar regions during their long winter night give a faint idea of what the whole Earth would be like without his warming and vivifying rays. He obviously governs the seasons—it is summer when he passes high in the sky, and is visible for considerably more than half the twenty-four hours, and winter when the conditions are reversed. Rough observations suffice to show that these changes repeat themselves in a period of $365\frac{1}{4}$ days, as was discovered in very ancient times.

WHAT THE SUN TEACHES ABOUT THE EARTH.—The Sun teaches us that our Earth is not of indefinite extent, but floating freely in space; for he obviously passes under us at night, and this not always in the same place (in which case we might imagine a tunnel for him to pass through), but at widely differing points in summer and winter. Indeed, if we went to Bodo, on the Arctic Circle, we might see him pass up or down at every point of our horizon, showing that our Earth is absolutely free from any support. Moreover, if we travel over the Earth we shall find

that the sun does not alter in apparent size, showing that his distance is immensely great compared with the Earth's dimensions.

SIZE AND SHAPE OF THE EARTH

SIZE AND SHAPE.—Having once persuaded ourselves that the Earth is not an indefinite plane, it is important to find her shape and size. The phenomenon of a ship disappearing below the horizon as she recedes—hull first, and finally the tops of the masts—shows us that the Earth's surface is curved, and as the curvature appears to be the same in all directions, and at all parts of its surface, we conclude that it is a sphere. We can get a rough idea of its size by a method used in Egypt by Eratosthenes. He found that the midsummer sun shone vertically down a well at Syene (Assouan), while at Alexandria at the same time it was found, by observing the shadow of a vertical pillar, to be distant from the overhead point by $7\frac{1}{4}$ degrees, or one-fiftieth of the whole circumference. Taking the distance between the stations as 5000 stadia, he deduced for the circumference fifty times this, or about 29,000 of our miles.

MODERN MEASUREMENTS.—The modern method is similar in principle, but far more exact. A base line of a few miles long is most carefully measured with rods or chains; from this the survey is extended in a series of triangles till it covers several hundred miles. Then the angle between the extreme stations is determined by measuring the distances of some well-known heavenly bodies from the overhead point at each station. Such arcs being measured in various regions, the earth has been found to be almost spherical; the distance from pole to pole is 7900 miles, the diameter of the equator some 26 miles longer.

JEANS' THEORY.—In 1903 Mr. Jeans suggested that the earth has a tendency to a pear shape, England being near the blunt end, and the stalk end being in the Pacific. This form being unstable, there is a tendency for the equator to become circular. He thus accounted for the prevalence of earthquakes in the regions midway between the two ends of the pear. The departure of the equator from a circle is very slight, only a mile or two, and the point is only mentioned here to avoid returning to it later.

ROTATION OF THE EARTH

APPARENT MOVEMENTS OF THE HEAVENLY BODIES.—We now return to our contemplation of the heavenly bodies, and note that there is one feature common to them all, *i.e.* they all have a common motion round us in twenty-four hours. There are two poles in the sky, one near the pole-

star, the other in the southern heavens; the whole firmament appears to rotate about the line joining these. Simplicity alone would lead us to conclude that it is the Earth, not the heavens, that is spinning, especially as we shall find that the different bodies are at vastly different distances, so that it would be inconceivable that they should all go round us in the same time.

FOUCAULT'S PENDULUM.—An absolute proof is afforded by Foucault's pendulum experiment. The pendulum is free to move in any plane, and, if started at the pole, would really retain its plane of rotation unaltered, but it would appear to turn right round in twenty four hours. In other latitudes it takes longer to complete a revolution, the duration being twenty-four hours \times cosecant latitude, so that at the equator no shift at all would be visible. Such a pendulum was recently swung from the dome of the Panthéon in Paris, the results agreeing well with theory. Even if the sky were always cloudy, and we never saw any heavenly bodies, it is possible that we might have discovered the rotation of the Earth by the behaviour of a Foucault pendulum. It is the centrifugal force arising from the rotation that causes the Earth's equator to bulge out.

THE MOON

After the Sun the next body to attract our attention is the Moon, "the lesser light that rules the night". Unlike the Sun, she appears to continually change her shape; but it is easy to prove that the change is apparent only, for with a telescope we can see that the invisible part is really there by its extinguishing stars when it comes to them. Examination will show that the Moon's changes depend on her distance from the Sun; when she is near him in the sky she appears as a thin crescent, and widens out as she recedes from him. The explanation is that the Moon, like the Earth, is a non-luminous sphere, only shining by reflecting the sun's light. We thus find that our first impression was incorrect, and that the Earth is quite similar in nature to some of the bodies around her.

THE SOLAR SYSTEM

THE PLANETS.—If we examine the sky carefully, and map out the positions of the stars, we shall notice that most of them retain their configuration unchanged, but a few bright ones will be found to be travelling through the heavens, some quickly, some slowly. These are the five planets (wandering stars) of the ancients, *i.e.* Mercury, Venus, Mars, Jupiter, Saturn, which, with the Sun and Moon, gave their names to the

days of the week, the connection being in some cases more easily traceable in the French than in the English names of the days. These bodies, like the Moon, are non-luminous globes, shining merely by reflection from the Sun. This is shown, in the case of the first three, by their exhibiting phases like the Moon, when examined with a telescope; in Jupiter's case, by the black shadows which his moons cast on his disc when they pass between him and the sun; and in Saturn's case, by the shadow cast by his ring.

THE SOLAR SYSTEM.—It has been recognized since the time of Copernicus that our Earth must be reckoned as a planet. The fact that she shines like them is proved by the faint light which can be seen on the darker part of the Moon's disc when only a thin crescent is lit up by the Sun; this light has come from the Sun to the Earth, thence to the Moon, and then back again to the Earth. Many other planets have since been discovered, and the whole assemblage, together with numerous comets and meteors or shooting stars, forms the "Solar System", or Sun's family; He is the source of their light and heat, while his attractive power keeps them circling round him; were this to cease, they would rush off into the gloom of outer space.

LIFE HISTORY OF THE EARTH.—A careful study of the different worlds of this system is of great help in revealing the story of our Earth's past; for just as in a forest we see trees in all stages of growth, from the acorn to the gnarled old oak, so we find worlds in various stages of development, and can form plausible conjectures as to the order of these stages. This method was used by Proctor, and, if carefully applied, is of great use in Astronomy. But just as in the forest we should make a mistake if we assumed that every tree we saw was a stage in the life history of the same organism, so we must not take it for granted that the different planets are all passing through identically the same career, though there is likely to be a strong family resemblance between them, just as the life history of a beech is very like that of an oak.

DISTANCE OF THE MOON

GENERAL METHOD.—In making a comparative study of worlds, one of the first points to consider is that of their size, to measure which we must determine their distance and their angular diameter. The distance is found by methods similar to those employed in surveying, *i.e.* a base line is measured, and the distant object observed from the two extremities of this; we then know one side and two angles of the triangle, and can find

the other sides by the rules of trigonometry. Knowing the distance and the angular diameter of the object, its true size follows at once.

APPLICATION TO THE MOON.—For example (fig. 1), let the two ends of our base be Greenwich and the Cape (which we shall, for simplicity, suppose to be on the same meridian). Let GC denote the two stations; EM the centres of Earth and Moon; and let GS, CS be lines drawn to a fixed star S , due north of the Moon; we shall find that GS, CS are to all intents absolutely parallel. The angles SGM, SCM must be measured; their difference gives us GMC . The altitudes TGM, TCM of the Moon at the two stations must also be measured. Then our previous knowledge of

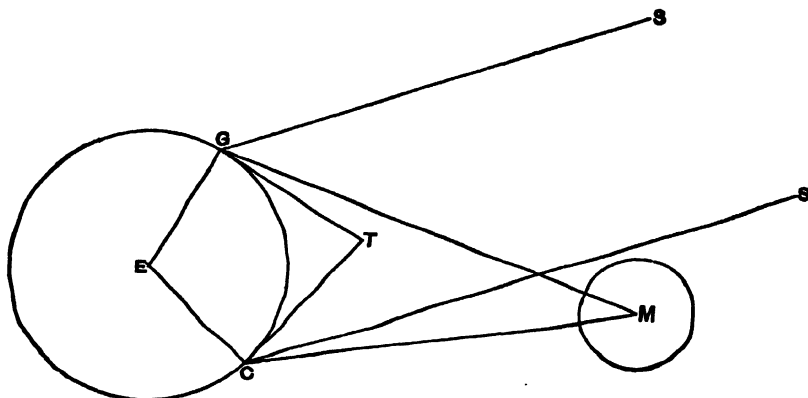


Fig. 1.—Determination of Moon's Distance

the size and shape of the Earth, and the latitudes of the two stations, gives us the angles TGC, TCG , and the distance GC ; we thus know all the angles and one side of MGC , and can deduce the remaining sides. The Moon's distance from the Earth is not constant, but its average value is found to be 239,000 miles. The diameter in miles of a heavenly body is its distance divided by 206,265 and multiplied by its diameter in seconds. The latter being 1865" for the Moon, we find for her diameter in miles 2160, or three-elevenths of the Earth's.

DISTANCE OF THE SUN AND PLANETS

TRANSITS OF VENUS.—The geometry of the motions of the planets gives us their relative distances very accurately; hence it suffices to measure the distance in miles of those that approach nearest to us, by the method already described, and all the rest can be immediately deduced. The first planet used for this purpose was Venus, when crossing the Sun's disc as a black spot. Expeditions were sent to various stations, and the exact instant

noted at which Venus entered wholly on the Sun's disc; the difference of these times enables us to find Venus's distance. These transits of Venus are very rare. The pair in 1761, 1769 gave the first reliable value of the Sun's distance, making it 95,000,000 miles; the pair in 1874, 1882 were very carefully observed, but the results were less accordant than hoped for, owing to apparent distortion in Venus's shape as she enters on the Sun.

EROS.—In 1898 a new planet was found, tiny Eros, which is at times our nearest planetary neighbour. Such an approach occurred in 1901, when thousands of photographs of Eros and surrounding stars were taken at all the observatories of the Northern Hemisphere. These photographs give the means of measuring with extreme accuracy the shift of Eros among the stars, as seen from different stations, and hence finding its distance.

DISTANCE OF THE SUN.—The accepted value of the Sun's distance is 93,000,000 miles. This is probably within 200,000 miles of the truth. The difficulties of the problem are very great, for the distance is 12,000 times our longest terrestrial base. Hence the change in the estimate is not surprising, and it should be pointed out that it cannot mean a real change in the distance, for that would involve a change in the length of the year, which we know has not occurred.

THE SPEED OF LIGHT, AND DISTANCE OF THE SUN.—Another method of finding the Sun's distance may be briefly mentioned. It has been found that the speed of light through space is finite, though very great, and all the heavenly bodies consequently seem to be shifted slightly towards the point whither the Earth is moving, just as running through a shower of vertical rain causes the rain to beat in our faces. The effect is to make each star describe a little ellipse in the course of a year, the length of which is the same for all (41"). We can deduce the ratio of the Earth's speed to that of light, and the latter has been found by careful measurement over a base of several miles, using a rapidly revolving mirror. The resulting speed is 186,328 miles per second, which would take it from the Sun to the Earth in 500 seconds. The value 93,100,000 miles has been deduced, which is practically identical with that given above.

STATISTICS OF THE SOLAR SYSTEM

The planets all move round the Sun in orbits that are practically circular, though the Sun is appreciably out of the centre of many of them. It will save space to give many of the particulars of their size, mass, and distance in the form of a table.

| Planet. | Distance from Sun in Millions of Miles. | Period. | Diameter. Miles. | Mass. Earth's = 1. | Density. Earth's = 1. | Time of Rotation. Equator. | Time of Rotation. Temperate Zones. |
|---------|---|-----------------|------------------|--------------------|-----------------------|----------------------------|------------------------------------|
| Sun | | | 867,000 | 333,400 | 0.254 | d. h. m. 25 9 8 | d. h. m. 27 0 0 |
| Mercury | 36.0 | days. 88.0 | 3,200 | $\frac{1}{33}$ | 0.66 | ? | |
| Venus | 67.2 | 224.7 | 7,600 | 0.82 | 0.93 | ? | |
| Earth | 93.0 | 365.3 | 7,926 | 1 | 1 | 0 23 56 | same |
| Mars | 141.7 | 687.0 | 4,210 | $\frac{1}{8}$ | 0.74 | 0 24 37 | same |
| Jupiter | 483.9 | years. 11.86 | 89,000 | 318.3 | 0.24 | 0 9 50 | 0 9 56 |
| Saturn | 887.5 | 29.46 | 76,000 | 95.2 | 0.12 | 0 10 14 | 0 10 37 |
| Uranus | 1784 | 84.0 | 31,000 | 14.5 | 0.24 | ? | |
| Neptune | 2793 | 164.8 | 33,000 | 17.1 | 0.24 | ? | |
| Moon | From Earth. 238,800 miles. | days. 27.32 | 2,160 | $\frac{1}{81.5}$ | 0.61 | 27 7 43 | same |

SATELLITES.—All the planets, except Mercury and Venus, are accompanied by satellites, and the observation of their periods and distances enables us to deduce their primary's mass; that of Venus is known by the disturbances it produces in the Earth's motion, but we can only guess at that of Mercury, since it is too small to sensibly affect its neighbours.

THE SUN AND INNER PLANETS.—Several points in the above table call for comment. (1) We notice how enormously the Sun outweighs the sum of all the other bodies (in fact, 740 times), so that he reigns as absolute monarch. (2) We see that we may divide the planets into two groups—the four inner ones being comparable with the earth in size, while the outer four are much larger. (3) There is a most interesting fact about the densities. We might expect that the larger bodies, by their greater attractive power, would have their materials more tightly packed; but we see that the reverse is the case, the Earth being the densest of all, while the Sun's density is quite low. We obviously seek an explanation in his very high temperature, from the well-known laws of expansion. The surface of the Sun appears to be in a gaseous condition, and it is probable that this state of things persists to a great depth, until the excessive pressure produces a quasi-solid condition.

THE OUTER PLANETS.—We next turn to the large planets, and here, too, the small density probably arises from a high temperature. We have evidence of this in the very rapid changes of the surface markings, and in the remarkable variations in the rotation times for different zones. These points indicate a resemblance to the Sun and some inherent source of

energy in the planets, since their distance from the Sun is so great that his heat would be inadequate to produce such effects. The Earth itself has a high internal temperature, as is shown by volcanic action, hot springs, and the rapid rise in temperature found in mines and other deep borings. The Moon's surface, again, bears evident traces of a past period of fiery activity.

LIFE HISTORY OF THE PLANETS.—We have thus a strong case for concluding that all the bodies of the system began their career as sun-like bodies, and that the smaller ones have been the first to cool. Most systems of cosmogony ascribe this primitive heat to the coming together of the constituent particles of the body from a distance, and the conversion of their kinetic energy into heat; there is, however, great variety in the details. Quite lately a further possible source of heat has been found in the radio-active elements, but it is not yet possible to form a quantitative estimate of the amount due to this cause.

CHAPTER II

THE SUN

HEAT OF THE SUN.—We naturally turn first to the Sun to get an idea of the condition of heavenly bodies in their fiery stage. Dr. Langley made measurements of solar heat on the summit of Mount Whitney, 14,000 ft. high, and arrived at the conclusion that if the Sun were surrounded by a shell of water 1 centimetre thick, with a diameter equal to that of the Earth's orbit, the temperature of this shell would rise about $3\frac{1}{2}^{\circ}$ C. per minute. On the assumption that the Sun's heat results from contraction of his mass, Professor Newcomb has deduced a contraction of about 1 mile in 20 years. Lord Kelvin similarly found 20,000,000 years to be the past duration of the Sun, on the assumption that his output of heat had been uniform, and resulted from the contraction of his particles from an infinite distance. These estimates make no allowance for the radio-active elements, which may modify the result to an unknown extent.

THE PHOTOSPHERE.—The Sun's visible surface is known as the *photosphere*. It is concluded that this must be of a cloudlike nature, since, if either solid or liquid, it would lose heat so rapidly by radiation that it would soon cease to be luminous. We must suppose strong convection currents to carry down the cooled matter and bring up new heated matter,

and nothing but gas has the required mobility. We do not know to what depth this mobile layer extends, but Dr. See has deduced that near the centre, even if the matter remain gaseous on account of the immense temperature, it would behave practically as a solid, the almost inconceivable pressure rendering it more rigid than any metal. Professor Sampson reached a different conclusion, *i.e.* that the pressure below a certain depth might remain nearly constant, and the convection currents extend to the centre. He has been able in this way to explain one peculiarity already mentioned—the rapid increase in the rotation period as we proceed from the equator to the poles; it is shown that this would arise if the rotation were much more rapid at the centre and continually diminished outwards.

SUN SPOTS

DISTURBANCES IN THE SUN.—On any view the visible surface of the Sun must be a scene of tremendous turmoil; its effects are seen during total eclipses in the red prominences, which are mighty eruptions of glowing gas flung with tremendous speed to heights of (say) 100,000 miles. They can be seen without an eclipse by the aid of the spectroscope. The sun spots are another evidence of mighty disturbance; they are huge rifts in the photosphere exposing a less luminous region, or perhaps filled with absorbing matter that veils the bright surface, and they show by their whirlpool-like structure and rapid change what mighty forces are at work.

SIZE AND SHAPE OF SUN SPOTS.—They sometimes attain a diameter of 50,000 miles or even more, and at such times are plainly visible to the eye if the glare be reduced by smoked glass or by fog. They are almost certainly depressions in the photosphere, though not of great depth, as is shown by their sometimes exhibiting the perspective of a hollow as they approach the edge of the disc.

SOLAR CYCLE.—One of the most marvellous and mysterious features of the spots is the periodic waxing and waning in a period slightly over eleven years. No clue to the cause has yet been obtained, but it is almost certainly inherent in the Sun itself, not arising from external bodies such as Jupiter, whose period is near it but not near enough. Comparison has been made with the intermittent action of geysers, &c., which have a calm period after an outburst, till the pent-up forces have again accumulated. We can scarcely say whether such action is possible in the interior of the Sun. All the solar appendages share in the fluctuation, and it is evidently not a mere surface phenomenon, but very deep-seated.

SUN SPOTS AND MAGNETISM OF THE EARTH.—The Earth's magnetic phenomena fluctuate in sympathy with the solar cycle, and Mr. Maunder has recently shown that the connection is very close, and that the period of the Sun's rotation can be detected in our magnetic disturbances. He deduces from this that these disturbances result from an action proceeding from certain regions of the Sun in definite directions, which regions are generally those of spots; but in some cases a region seems to retain its activity after the spot has closed up. He suggests that the disturbance may be transmitted to the Earth by the actual discharge of very minute particles, possibly small enough to be affected by the pressure of light, which produces on very tiny bodies a stronger action than gravitation. The great permanence of the affected regions on the Sun is a surprising feature, considering the mobility which the Sun's surface must have.

SHIFT OF SUN SPOTS.—During the eleven-year cycle the spots have a remarkable shift in latitude; just after spot minimum they break out in high north or south latitudes, and then gradually close in on the equator, to which they make their nearest approach at the next minimum, when the cycle begins anew. The cause of this movement is as mysterious as that of the spot cycle.

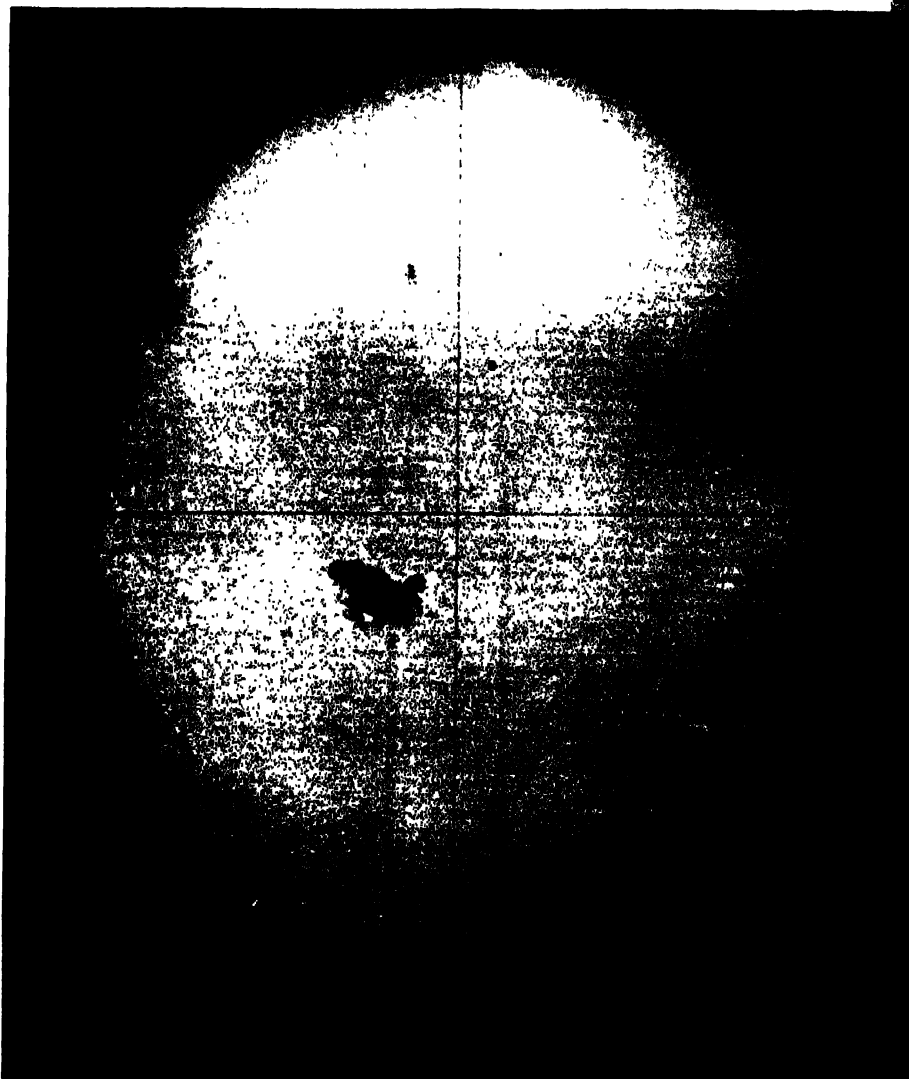
THE SUN'S ABSORBING ATMOSPHERE

The Sun's disc becomes decidedly less luminous near the limbs, the cause being the same as the diminution of light of the setting Sun, viz. greater absorption owing to the light traversing a greater depth of atmosphere; but in this case the atmosphere is that of the Sun. The solar atmosphere is a few hundreds of miles high, and its constitution can be found by the spectroscope.

This instrument splits up the Sun's light into a rainbow-tinted band, crossed by thousands of dark lines caused by the absorption of light by the gases in his atmosphere. Comparison with the spectra of known substances enables us to identify many of the gases present in his atmosphere. Hydrogen and calcium are abundant, also iron, sodium, magnesium, and a number of others. It is of interest to note that just as our air makes the Sun look red when setting, so the Sun's atmosphere absorbs more of the blue light than of the red, and in consequence the darkening at his limb is more conspicuous in photographs than to the eye (for the blue rays are more efficient photographically). The golden tinge of his light is due to this smoke veil; were it removed, he would look bluish.

THE SUN

This is one of the photographs of the Sun's disc taken at Greenwich Observatory every fine day (reproduced by kind permission of the Astronomer Royal). The cross lines are wires in the instrument used for determining the true bearing of the spots. The darkening towards the edge of the disc shows the absorption of the Sun's atmosphere. The enlargement of the Great Spot shows *umbra* and *penumbra*, and the formation of bridges by the inrush of luminous matter.



THE SUN

SUN-SPOT THEORIES

NATURE AND ORIGIN OF SUN SPOTS.—Spots when examined with the spectroscope show a general darkening, and also widening and contortion of the lines. This indicates that they are cooler regions, and also under greater pressure, thus confirming the idea that they are depressions. There are two principal explanations: (1) that they are caused by the downrush of cooler matter from without; (2) that great explosive rushes of gas are taking place from the interior; the gas on reaching the surface would expand rapidly from diminished pressure, and in consequence would cool. The second view seems to the writer the more probable, especially as the spots are found to be intimately associated with the prominences which are obviously eruptions. The tendency of contemporary spectroscopists is, however, towards the other view.

PARTS OF A SUN SPOT.—Spots and their surroundings consist of four parts: (1) The *nucleus*, a small black spot in the middle, which would be the funnel up which the uprush had come; (2) the *umbra*, or dark region, where the bright photospheric clouds are torn aside; (3) the *penumbra*, or greyish region, perhaps due merely to greater absorption, owing to its depression below the general surface; (4) the *facula*, or bright wave surrounding the spot, doubtless the displaced photospheric matter traveling outwards. They rise above the general level, being sometimes seen as ridges on the limb. They are much more conspicuous near the limb than in the centre of the disc; this is owing to contrast, for, being above the surface, they would not suffer so much absorption as the surrounding photosphere.

HALE AND ADAMS'S THEORY.—Professors G. E. Hale and W. S. Adams have recently advanced a new theory of spots, based on their spectroscopic observations, combined with Professor Fowler's work on the spectrum of titanium oxide. They have succeeded in identifying the titanium flutings in the spot spectrum, and find that the lines that are strengthened in this are those that are strengthened when the vapour producing them is lowered in temperature. Hence they conclude that a spot is a region of lowered temperature, and that the Sun's atmosphere over it is modified by this lowering; but that the upper layers of this atmosphere are less cooled, so that the temperature gradient is reversed. The titanium producing the banded spectrum is supposed to lie at a great depth, where the temperature is so low that, being a very refractory substance, it is imperfectly vaporized; while the substances producing the line spectra are higher, and are completely vaporized.

This theory also accounts for some bright lines having been seen in spot spectra; these would arise from upper vapours, and their higher temperature would account for the brightening. We shall recur to the discovery of the lines of titanium in spot spectra when we deal with variable stars, and we shall see that it is full of significance, indicating that our Sun is at an incipient stage of star variability. Hale and Adams have searched for evidence of the shifting of lines, denoting motion in the line of sight. They find very little trace of such motion in umbrae, that little being in a downward direction; they find, however, uprushes in the bright bridges of spots and at adjacent regions of the photosphere.

ASSOCIATED SUN SPOTS.—Large spots are generally accompanied by groups of smaller ones, sometimes of immense length, and more or less regular sequences in their behaviour have been traced—sometimes there seems to be a tendency for one to rotate round another. Their duration varies greatly: small spots may only last a day or two; large ones frequently do not persist for a second rotation, but sometimes they last much longer; allusion has already been made to repeated outbreaks in the same region. The disappearance is effected by the inrush of the surrounding faculae, forming bridges, and splitting up the spot into smaller ones, which gradually disappear. The contortion in the spectral lines in spots is due to rapid motion of approach or recession in the luminous gases; this alters the wave length of the light, and shifts the lines. The violence of the explosions is shown by the great speeds attained—hundreds of miles per second. These speeds are verified by the rapid changes in the prominences which take place under the eye of the observer; the matter moves up visibly, attains a tremendous height, and then bends over and descends.

THE SPECTRO-HELIOGRAPH

FLOCCULI AND CHROMOSPHERE.—During recent years a new and powerful weapon of research—the *spectro-heliograph*—has been introduced. This takes photographs of the sun in light of one colour only, the slit of the spectroscope being moved over the disc, and the photographic plate being moved to correspond. The portions of the spectrum generally chosen are the hydrogen or calcium lines, and a new feature has been revealed, *i.e.* that there are immense clouds—*floculi*—of these gases in the sun's atmosphere. They occur chiefly in the spot zones, and sometimes cover up the umbra of a spot, though entirely invisible to ordinary sight. The instrument can also be used for taking simultaneous photographs of disc and prominences, valuable for tracing the connection

between the two. There is generally a layer of prominence matter right round the sun (outside the true atmosphere); this is known as the *chromosphere*, and the eruptive prominences rise out of it.

THE CORONA AND TOTAL ECLIPSES.—There is still another solar appendage—largest, though least massive of all,—the filmy *corona*, which can only be seen during total eclipses, and which sometimes extends millions of miles above the limb. As total eclipses are rare phenomena, and frequently require long journeys for their observation, and as the duration of totality seldom exceeds four minutes, the growth of our knowledge of it has been slow. More has been done of late years, as the introduction of photographic methods gives reliable information respecting both the shape and spectrum of the corona. The light of the lower part, near the sun, is so great that we can understand how the early astronomers took it for part of the sun's disc, and thought no eclipses could be total. It fades off rapidly, and the outer portions are most delicate and ethereal, requiring perfect weather conditions to detect them.

CORONA AND SPOT CYCLE.—It has now been established that the corona changes with the spot cycle. At maximum it is arranged symmetrically round the limb, so that we could not tell from looking at a photograph which was the direction of the equator; but at minimum there is a great extension in the equatorial regions, while the poles are only occupied by the *polar plumes*, a series of beautiful, thin, curved rays strongly recalling the magnetic curves produced by iron filings, so that many astronomers have attributed them to magnetic action. A characteristic feature of the long coronal streamers is their *synclinal* curvature, *i.e.* the portions nearer the sun have convex boundaries, then there is a *point of inflection*, and the boundaries of the outer portion are concave.

The longest ray of this kind ever photographed (by Mrs. Maunder in India in 1898) was traced with certainty for a length of 6 diameters (5,000,000 miles), and was suspected for 7 diameters. Mr. Maunder conjectures that streamers like this may exemplify the kind of action that he postulates to carry to the earth the tiny particles that are supposed to produce our aurora and magnetic storms; probably the matter forming them is so finely divided that light pressure is stronger than gravitation, and propels them away from the sun.

COMPLEXITY OF CORONA.—The corona is probably a highly complex structure; some parts of its light are due to solid particles reflecting the Sun's light, or, if very near him, perhaps heated to incandescence, and shining by their own light. Another portion is shown by the spectro-scope to consist of an unknown gas, to which the name *coronium* has

been given; it is presumably lighter even than hydrogen. The ethereal nature of the corona was emphasized by the comet of 1882, which passed through it, and, though itself of most filmy structure, escaped without any sensible retardation of its motion. Curious dark structures are sometimes seen in the corona and prominences which may be due to some intervening streams of matter. Similar structures occur in nebulae, and may be due to a similar cause on a grander scale.

CORONA AND DISC DISTURBANCES.—Recent eclipses have established a connection between the coronal structure and the disturbances on the disc. Over a strongly disturbed region were seen a number of concentric arches, recalling the circular waves made by a stone thrown into water, and probably the result of an explosive outburst.

CHAPTER III

THE GIANT PLANETS—JUPITER, SATURN, URANUS, NEPTUNE

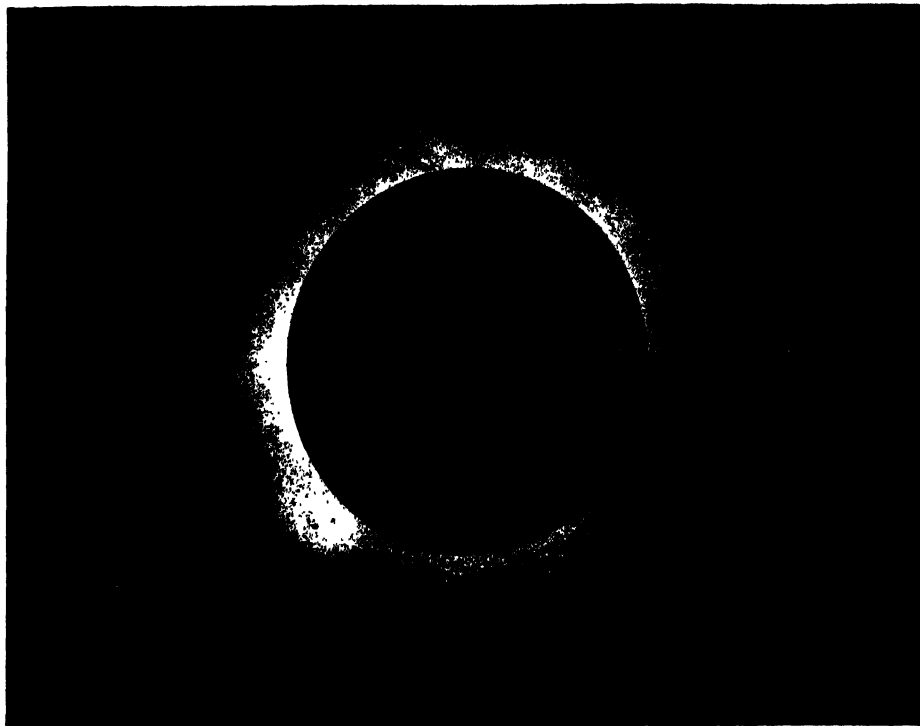
JUPITER

We proceed now to the giant planets, which illustrate the stage in a world's career when it has ceased to have an incandescent photosphere, but is still agitated by internal heat (fig. 2). Jupiter is in every way the best world to take as our type, since he is at once the largest and the nearest of the four giant planets. Saturn, however, resembles him closely, except for the added feature of the ring. We can never hope to learn much of Uranus and Neptune, owing to their great distance; but their low density probably indicates general similarity to the other two.

SIZE AND APPEARANCE OF JUPITER.—Jupiter's bulk exceeds that of the Earth more than a thousandfold, but his mass only three hundredfold. This fact in itself suffices to prove that a large portion of his bulk is gaseous, and observation fully bears out this idea. We probably never see the planet's real surface, but only an immensely deep cloud layer. The clouds are not distributed at random, but are generally arranged in belts parallel to the equator (fig. 3). These belts are continually changing, and produce the impression of a series of cloud layers, one behind another down to an immense depth. It is to be remembered that he is at five times the earth's distance from the sun, so the solar heat would be quite inadequate to produce these clouds. Indeed, were the planet

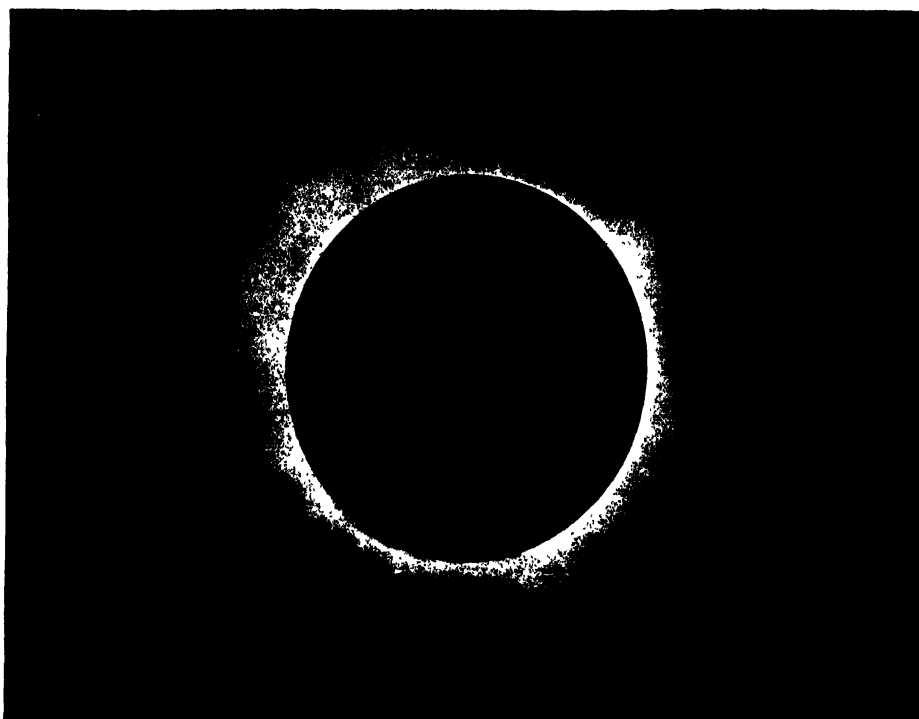
CORONA

The coronal types of sunspot maximum and minimum are clearly shown in these two plates (reproduced by kind permission of the Astronomer Royal). At maximum the streamers are distributed round the whole disc fairly equally, at minimum they are confined to the equatorial regions, except for the delicate thin appendages known as the polar plumes.



CORONA OF SUNSPOT MAXIMUM

PHOTOGRAPHED BY THE ASTRONOMER ROYAL AT SFAX (TRIPOLI), AUGUST 30, 1885



CORONA OF SUNSPOT MINIMUM

PHOTOGRAPHED BY THE ASTRONOMER ROYAL AT OVAR (PORTUGAL), MAY 28, 1900

dependent on the sun alone for heat, a terrible frost would prevail, and all moisture would probably be precipitated. The heat must therefore be inherent, but the atmospheric veil hides from us the probably still glowing surface.

THE BELTS OF JUPITER.

—The parallelism of the belts to the equator reminds us of the solar-spot zones, and there can be no doubt that both are rotation effects. There is the further analogy that the equatorial regions rotate more rapidly than the rest; the actual times are 9 h. 50.5 m. and 9 h. 55.7 m. The range is much less than in the Sun's case, and the period does not, as in that case, gradually increase with the latitude; but all the markings seem to conform pretty closely to one of these values.

LIGHTS AND COLOURS OF JUPITER.—Some have supposed that Jupiter may still give a little inherent light. His disc is very brilliant, considering the distance from the sun, and as large regions are obviously dusky it may well be that the brighter regions shine partly by their own light. That the amount of this is small, however, is shown by the blackness of the shadows of the satellites, and the total disappearance of the latter when they enter the shadow of their primary. Very rich and beautiful colours are shown on the disc. Mr. W. R. Waugh says of the bright equatorial zone: "Its ruby-tinged golden hue has made it attractive to students and beautiful to behold. What can be the cause? An additional

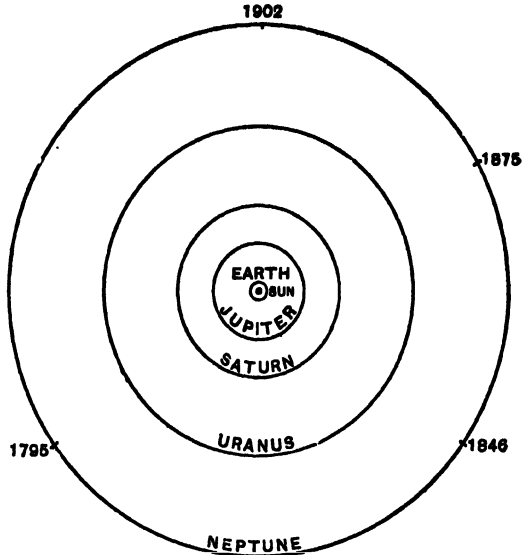


Fig. 2.—Orbits of the Earth and of the four giant planets. Periods in years: Jupiter 12, Saturn 30 (nearly), Uranus 84, Neptune 165. The positions of Neptune are shown at the dates 1795 (first observed as a star), 1846 (discovered as a planet), 1875, 1902. In 1960 it will return to the position of 1795.

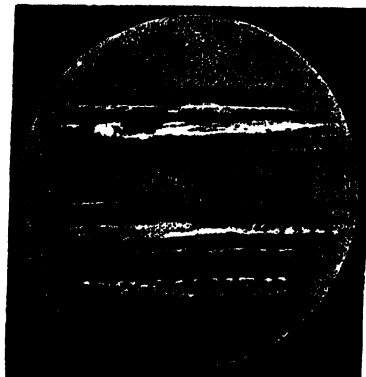


Fig. 3.—Jupiter. (From a sketch by Dr. D. Smart.)

increase of heating power is perhaps the most feasible explanation. From belt to belt it seemed to glow in coloured light." Other regions are described by Mr. Lassell as purple, brown-orange, and light olive-green; others speak of blue, crimson, and sea-green.

THE GREAT RED SPOT.—One of the most remarkable coloured regions is known as the Great Red Spot. This is an enormous ruddy oval marking, 150,000,000 sq. miles in area (three-fourths of the whole surface of the Earth), which has persisted since 1879. There is some evidence of a similar outburst having previously taken place on the same part of the planet, which calls to mind the recurrence of solar disturbances in the same region. Many have thought that it is either the surface of the actual glowing planet or a thin cloud stratum transmitting that glow.

Mr. R. A. Proctor says:

"When the whole spot was red, the region thus disclosed lay below the general level of the cloud surface we see and measure, probably by many hundreds of miles. The red light was in part inherent, but probably the actual region whence inherent light proceeded lay far below the surface from which it appeared to emanate. The existence, long continuance, and rapid changes of appearance in the great spot indicated an activity in Jupiter's mass corresponding well with the theory that he is in a condition between that of a Sun like our own and that of a world like our Earth."

The spot has not remained in absolutely the same position on the planet; it has, indeed, drifted over some 40 degrees of longitude. These changes have generally seemed capricious, but on two occasions a change of rotation rate has synchronized with the overtaking of the spot by a large dark marking which seemed to give it a sudden push onward. This probably implied that the red spot is not the actual surface, but a low cloud layer which had been pushed away from the actual seat of disturbance, but afterwards returned to it. In a somewhat similar manner Proctor explains the long rows of oval white clouds by supposing that they are the products of successive eruptions from the same region, but that an atmospheric current has carried them away from this region and spread them out in a band.

Other proofs of the great depth of Jupiter's atmosphere are afforded by the behaviour of the satellites when passing before or behind the disc. A well-attested case occurred in 1828, when three skilled observers (Admiral Smyth, Mr. Maclear, and Dr. Pearson) saw Satellite II pass on to the disc, and several minutes later appear again outside it, showing that a large area of the planet had become transparent and

invisible. This is supported by Mr. Todd's observations at Adelaide; on several occasions he saw the satellites through the limb after they had passed behind it.

SATURN

COMPARISON WITH JUPITER.—Saturn is Jupiter's brother giant, and much that we have said of the one applies also to the other. Both have rapid rotation, and in consequence great polar flattening; while both present to us a cloud surface crossed by parallel belts. Saturn is but little inferior to Jupiter in size, but his density is surprisingly small (one-seventh of the Earth's), so that his mass is only two-sevenths of Jupiter's. This leads us to conclude that he also is in a semi-sunlike stage. His equator rotates in ten and a quarter hours, while a white spot in the temperate zone gave a value twenty-four minutes longer. This difference of rate implies atmospheric currents of the speed of 1000 miles per hour. The existence of these great currents is also shown by the behaviour of the white equatorial spot used by Professor A. Hall in 1876 to deduce the rotation. This began as a round, brilliantly white spot, but quickly spread out eastward. This probably arose from the source of the eruption being at a great depth, and having a slower rotation than the surface, so that successive jets appeared farther and farther to the west.

SATURN'S RING.—The unique feature of Saturn is his encircling ring; nothing of the kind exists elsewhere in our system, though a parallel may be found among the nebulae, as we shall see later. It is not really a single ring, but a series of them, all concentric, and in the plane of the planet's equator. They are astonishing both from their immense size and their thinness; the latter can scarcely exceed 100 miles, and when the ring is edgewise, which happens every fifteen years, it vanishes in all but the finest telescopes, which reveal it as a delicate line of light.

COMPONENTS OF THE RING.—First comes the outer ring, with a span of 169,000 miles and a breadth of 9700. Next follows a great gap, 2200 miles wide, known as the *Cassini division*. Then comes the brightest ring, 17,000 miles broad; it is brightest on its outer edge, and grows darker inwards by slow gradations. Inside this, again, we have the *crape*, or transparent ring, through which the limbs of the planet can be seen. It is probable that this is somewhat thicker than the others, as when the system is edgewise it sometimes appears as a nebulous band. Its inner edge has been observed to present an irregular and jagged appearance, and it is probably subject to variations, since it was not detected by the great reflector of Sir W. Herschel, while it can now be seen in an ordinary telescope.

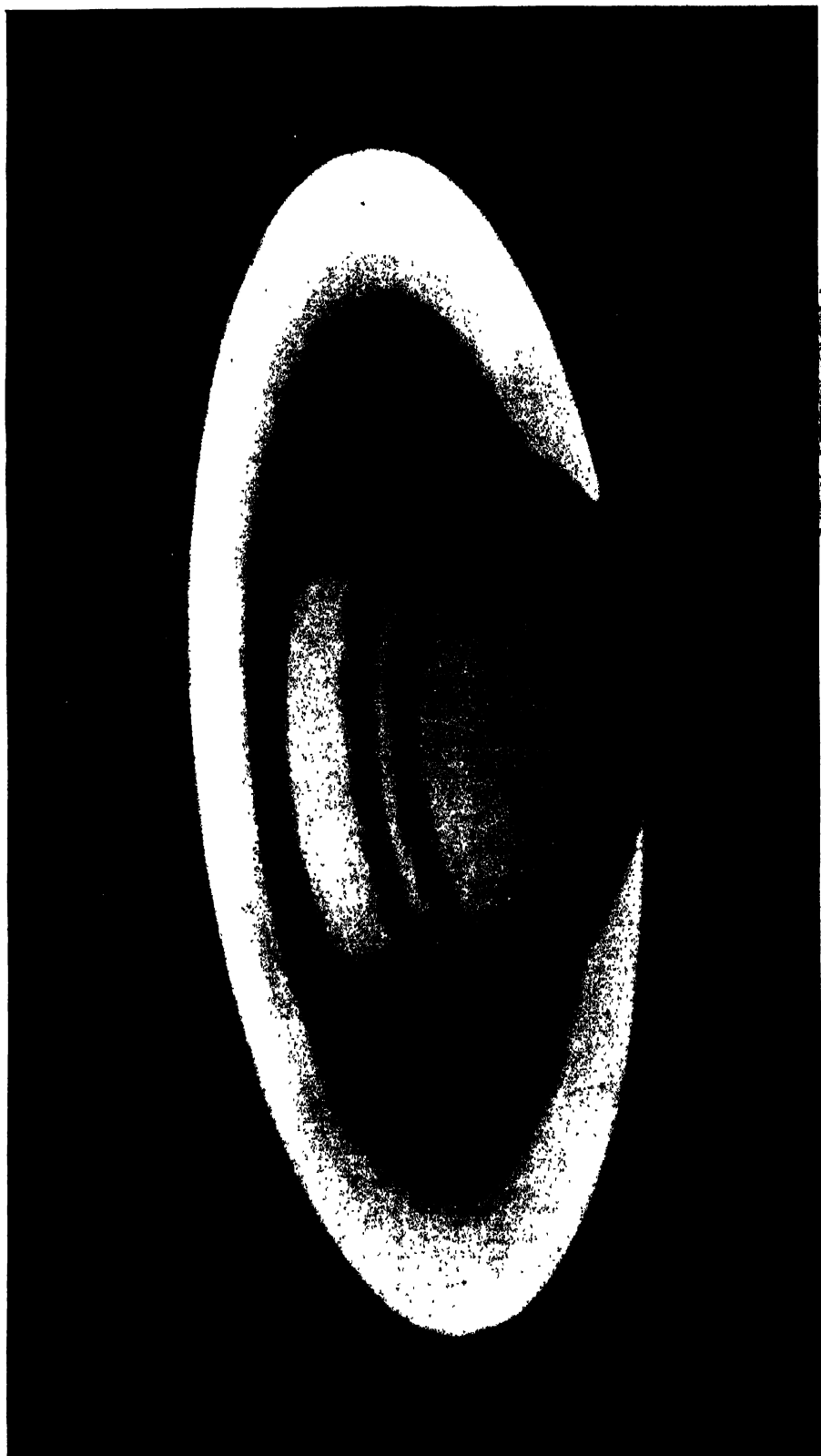
MOVEMENTS AND NATURE OF THE RING.—Sir W. Herschel found in 1789 that the ring was revolving round the planet. It is, indeed, pretty clear that otherwise the system would be as unstable as a needle balanced on its point. He gave the period as 10 h. 32 m., but it was proved by Mr. J. Clerk Maxwell in 1857 that the ring could not revolve as a solid continuous surface, but that each element must revolve separately at the proper speed for its distance from Saturn, since otherwise the enormous strains would tear it to fragments. In other words, the ring is a dense swarm of very minute satellites, each having its own period of revolution. Any doubt that might linger about this conclusion was dispelled lately by the application of the spectroscope, which showed the lines in the ring's spectrum bent in such a way as to show more rapid motion for the inner portions, in the exact ratio indicated by Maxwell. The particles of the crape ring are evidently thinly scattered, and permit the dark background of the sky, or the limbs of the planet, to be seen between them.

CHANGES IN THE RING.—The fact that the rings are a mass of discrete particles makes it probable that changes are in progress in their grouping. Proctor in *Saturn and its System* made out a good case for concluding that the system, since its discovery, had widened inwards very appreciably, so that the inner regions might be expected to reach the planet in a few centuries. More recent observations, however, have failed to support this inward motion. There can, however, be little doubt that such changes are in progress, though at a slower rate than Proctor supposed.

THEORETICAL IMPORTANCE OF THE RING.—The rings of Saturn are of great importance in discussing the mode of formation of our system, since they show either an early stage in the formation of a satellite, or an altered process, which in other cases has given birth to a satellite but here has only resulted in a cosmical cloud. There are some analogies between the ring and the zone of minor planets (asteroids) which revolve round the Sun between the orbits of Mars and Jupiter. The latter are far less densely scattered, but in each case there are zones of richness with barren regions between. The gaps in the asteroid orbits are known to be due to Jupiter's action, since they occur at distances from the Sun which correspond to simple fractions of Jupiter's period. In the same way the gaps in the rings are probably due to the perturbations produced by Saturn's satellites; in particular, the great Cassini division is at such a distance that its period is half that of the inner satellite Mimas.

SATURN

This plate shows the triple ring, and the transparency of the *craps ring*; also the irregular shadow of the planet on the ring. The curious shape may arise partly from irradiation, partly from actual irregularities in the ring's surface. The bright equatorial zone, belts, and dusky polar regions of the planet are shown.



URANUS AND NEPTUNE

PHYSICAL CONDITION.—Owing to their great distance little is known of the physical condition of the other two giant planets, Uranus and Neptune. From their low density, the same as that of the Sun and Jupiter, it is probable that they, too, are in a heated condition. From their much smaller size it is likely that they have progressed further towards the terrestrial condition. This view is, perhaps, supported by their spectra, which show broad absorption bands, much more prominent than those shown by Jupiter and Saturn.

ROTATION.—Their period of rotation is unknown, but is suspected to be less than twelve hours. Faint markings have been seen on Uranus, indicating a fairly rapid rotation, while in Neptune's case there is obviously considerable oblateness, since the plane of the satellite's orbit is found to be changing, evidently under the action of the planet's equatorial protuberance. These two planets have one striking peculiarity, viz. the high inclination of their satellites' orbit planes to those of the primaries. In the case of the other planets this angle does not exceed 30 degrees, with the single exception of Saturn's outermost satellite, Phœbe, which has a retrograde motion.

SATELLITES OF URANUS.—But the four satellites of Uranus all have a retrograde motion in a plane inclined 82 degrees to the primary's orbit plane, and it is practically certain that the planet's equator plane coincides with the satellites' plane, since otherwise his equatorial protuberance would cause their plane to have a rapid shift, of which the measures show no trace.

SATELLITE OF NEPTUNE.—Neptune's satellite has also a retrograde motion, its inclination being about 40 degrees; Neptune's equator is concluded to be inclined some 28 degrees to its orbit, its rotation being presumably retrograde. We shall return to these peculiarities of the outer planets when we discuss the probable mode of evolution of the solar system.

CHAPTER IV

THE TERRESTRIAL PLANETS—MERCURY,
VENUS, EARTH, MOON, MARS

MERCURY

PERIOD OF ROTATION.—We come now to the discussion of the class of worlds more or less resembling our own Earth. They are five in number. Mercury, Venus, Earth, Moon, Mars (fig. 4). But little is known of the physical condition of the first two. Mercury is small, and very near the

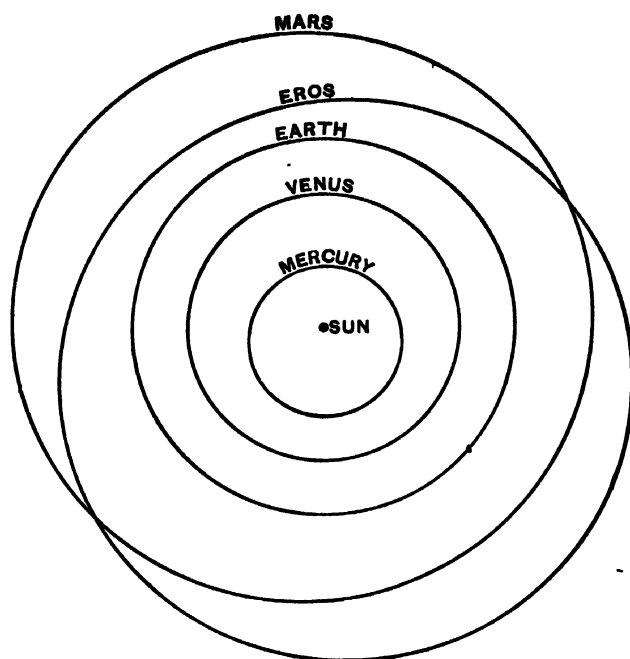


Fig. 4.—Orbits of the four terrestrial planets, also of Eros the tiny planet, whose orbit approaches ours so closely. The orbits are all very nearly circular, but the Sun is considerably out of the centre of some of them. Periods in days—Mercury 88, Venus 225, Earth 365, Eros 643, Mars 687.

sun, so that it is difficult to make good observations. Definite markings on his disc have been seen, but nevertheless the period of rotation is still quite doubtful. Some astronomers (notably Schiaparelli and Lowell) maintain that the period of rotation is the same as that of revolution, *i.e.* eighty-eight days, which would imply perpetual day for one hemisphere, perpetual night for the other; others hold that the period is only slightly longer than that of our Earth. The question is obviously of great im-

portance as affecting the habitability of the planet.

INHABITABILITY.—There is, however, another reason for deciding against the habitability of Mercury, a reason that is common to all worlds that are notably smaller than our Earth. It is deduced from the kinetic theory of gases, according to which all the molecules of the gas are in rapid motion, the mean velocity being greater in proportion as the gas is rarer. The speed of some of the molecules must be considerably above the mean, and probably every molecule would at some

time in its history attain the maximum speed. Now there is for each orb a certain speed which would suffice to carry a particle away from that orb. For the first four planets and the moon these speeds are 2.9, 6.2, 7.0, 3.2, 1.5 respectively (in miles per second). In the case of the Earth we know that only the lighter gases can escape, such as hydrogen and, perhaps, helium; thus, although there is much hydrogen on the Earth in compounds, it does not exist in a free state in our air, as it does in the Sun and giant planets.

COMPARISON WITH OTHER PLANETS.—The conditions on Venus are similar to those here, and observation proves that she has an atmosphere like ours. All the gases have sufficient speed to carry them away from the Moon, and observation shows that she is airless. Mercury would seem to be in nearly the same case; one fact revealed by observation is the low *albedo*, or reflective power of his surface. Now the giant planets and Venus, which are probably cloud-covered, have albedoes of one-half or more; Mars, which has evidently some air, has the value one-fourth; but the airless Moon has the value one-sixth, and Proctor gives a still lower value to Mercury, so that its condition is probably moonlike. The theory of the escape of gases is due to Dr. G. Johnstone Stoney, and it would follow from it that all the satellites and minor planets are airless, and it would appear that only one orb in the solar system could support life such as exists on Earth, *i.e.* the planet Venus, to which we now proceed.

VENUS

RESEMBLANCE TO EARTH.—Venus is the brightest of the heavenly bodies after the two "Great Lights", and she is interesting in her close resemblance to the Earth in size, mass, and atmosphere; but the telescopic study of her surface has proved very disappointing. The phases are easily visible, but very little more can be certainly detected, so that it is still doubtful whether she rotates in some twenty-four hours or in 225 days, the period of her revolution. Of her atmosphere there is no question; a decisive proof of its presence is afforded by the behaviour of the planet on the rare occasions when she appears to transit the Sun's disc. After having entered partially on the disc a ring of sunlight is seen, completing the portion still outside the disc; this can only arise from refraction, and it has been deduced that her atmosphere must be as dense as our own.

CHARACTER OF ATMOSPHERE.—Most astronomers consider that this atmosphere is permanently cloud-laden, and that we never see the real

surface of the planet. According to this view the faint markings occasionally observed are only variations in the colours of the clouds, so that the true surface might be rotating at quite a different rate from these, for there might easily be some reason which would make the clouds change their appearance before sunset, and, if so, the marking would not show any rotation.

Only one astronomer, Professor Lowell, considers that the atmosphere of Venus is cloudless. He has drawn a number of radiating canaliform markings, which he considers are on the actual globe, and he is confident in the reality of the slow rotation. He says:

"The markings are not only permanent but permanently visible whenever our own atmospheric conditions are not so poor as to obliterate all detail upon the disc. They are thus not evidently cloud-hidden at any time. But the whole disc, dark and light portions alike, is brightened as by a luminous atmosphere. When compared with the appearance of the disc of Mercury or of our own moon, the appearance of the disc of Venus is such as to make the presence of a very substantial atmosphere evident."

He then refers to a twilight arc being seen, and to the absence of distinctive colour, and says:

"The markings, which are of a straw-coloured grey, bear the look of being ground or rock, and it is presumable from this that we see simply barren rock or sand weathered by æons of exposure to the sun. The markings are . . . conclusive as to the period of rotation. There is no certain evidence of any polar caps. . . . The surface presents as dead an appearance as does that of our own moon."

This is an extreme view in one direction; to illustrate opposite views we may quote R. A. Proctor, where he says:

"She retains a larger proportion than the Earth of her original heat. Her atmosphere seems to be denser and more moisture-laden, even above the layers of dense cloud which enwrap her globe, covering both sea and land (but not perhaps in equal degree) at all times."

Similarly Professor W. H. Pickering remarks that this planet is:

"Completely enveloped by its oceans, as is presumably the case with Venus at present".

The spectroscope has been applied to the examination of the rotation period by Belopolsky and Lowell; they decide respectively in favour of the short and the long period, so that the question is still unsettled.

MARS

APPEARANCE OF DISC—POLAR CAPS.—We now pass from this beautiful but disappointing planet to Mars, our neighbour on the other side. Although he does not approach us quite so nearly, yet from being opposite to the sun, and presenting a fully illuminated disc on a dark sky, he is much more favourably placed for examination. Moreover, obscuration by cloud or atmospheric veiling is much less present, the result being that we know the surface of Mars better than that of any heavenly body after the Moon, and he is much more interesting than the Moon, being a living world on which processes of change can be clearly seen (fig. 5). The earliest important discovery was that the planet has *polar caps*, which can be easily seen to wax and wane with the march of the seasons. They show that the tilt of the equator to the orbit is 24 degrees, practically the same value as for the Earth ($23^{\circ} 27'$).

DUSKY AREAS.—There are a number of dusky areas on the planet which are quite easy to see, and have been known since 1666, when they were drawn by Cassini and Hooke. Unlike Jupiter's markings, they are on the whole permanent in position and appearance, though subject to slight variations. Hence they are on the solid ball of the planet, not merely atmospheric. They are of a greenish tint, while the bright areas are ruddy, and give the planet its distinctive colour. Obscuration by cloud is evidently very infrequent, in fact everything tends to the conclusion that the atmosphere is extremely rare. The small size and mass of the planet, and the clearness with which the markings are seen, all make this probable.

It used to be thought that the dusky areas were oceans, but this has been abandoned for many reasons: (1) Details of a permanent nature are seen on them, which could scarcely be the case on bodies of water; (2) Professor W. H. Pickering found no polarization in their light; (3) Dr Johnstone Stoney's theory of escape of gases tended to the conclusion that aqueous vapour would escape from the Martian atmosphere. This cannot be considered as quite certain, since there are good reasons for doubting whether the molecules of gases are subject to quite the same laws of motion as bodies of finite size.

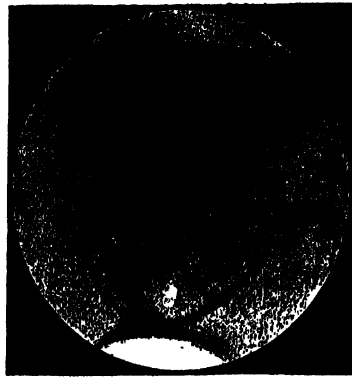


Fig. 5.—Mars. (From a sketch by E. M. Antoniadi)

NATURE OF POLAR CAPS.—If Stoney's theory is true, there can be no water on Mars, and the polar caps must be formed of some other substance. There is another reason for doubting whether these caps are frozen water. The distance from the Sun is one and a half times the Earth's, which would make the mean temperature less than half ours, or far below freezing-point, which is scarcely affected by alteration of pressure. But the polar caps evidently do melt or evaporate, and that with great rapidity, so that either they are not frozen water, or the Martian air has some property, like the glass of a hothouse, permitting heat to enter freely, but retarding its escape. The clearness of this air hardly favours such a notion, but it does not quite negative it. We cannot invoke any considerable amount of internal heat, for the polar caps obviously follow the seasons, and so are sun-melted.

CHARACTER OF SURFACE.—Till the middle of the nineteenth century most astronomers looked on Mars as a miniature of our Earth. This position is now generally abandoned, but there are two schools of thought regarding the condition of his surface. The first concludes that active processes of vegetational change are in progress, the other looks on the planet as a frozen desert. We shall describe extreme views in these two directions, though, of course, many intermediate ones are possible.

LOWELL'S THEORY.—Professor Percival Lowell is the leading exponent of the first view, and no one can accuse him of propounding it hastily or without careful study. He selected a station (Flagstaff, Arizona) where observing conditions are exceptionally good, and has studied the planet at every apparition since 1894. His view is that water has become scarce, the supply mainly depending on the melting of the polar caps. It is conducted over the surface by the canals, which are a complicated system of narrow streaks covering the whole surface, but especially the ruddy regions. They were first announced by Schiaparelli in 1877, though some had been drawn earlier by Dawes and others. Their reality was long questioned, but has now been proved by photographs taken at Flagstaff, showing many of them. All are agreed that the ruddy regions are deserts, and Lowell thinks that the streaks we see are the fertile strips (some miles wide) near the waterways, presenting the appearance that the Nile Valley would if seen from a like distance, flanked on either hand by the sandy desert.

He thinks the so-called seas are the more fertile regions, though the canals can now be traced even across these, implying that they, too, are dependent on them for their water supply. In support of his theory he describes how the markings darken progressively from the pole to

the equator after the melting of the snow. He also notes that when the period of vegetation is over, the regions turn yellowish again in the same order, implying the fading of the leaves. He also explains the mysterious doubling of the canals by supposing that the vegetation begins in the centre, and likewise fades there first, leaving two parallel streaks of green, with brown between. He has noted the position of the rifts in the polar caps during melting, and found them to agree with the known positions of canals.

Professor W. H. Pickering had noted in 1892 that there were dark spots at the junctions of canals which he called lakes. Lowell has confirmed these, but calls them *luci*, as suiting better their supposed character. The following quotation describes the colour changes that he has noted, which would certainly accord well with the vegetation theory:

"Of the large dark patches . . . the distinctive colour is blue-green. The tint deepens or lightens according to the season of the year, and in the antarctic regions fades in autumn to an ochre. For the greater part of the time . . . the robin's-egg blue is characteristic, and counterparts the tint which our forests take on, seen through a veil of intervening air. . . . I was surprised to note (on April 19, 1903) that the whole of the Mare Erythræum to the south of the Syrtis showed a chocolate-brown, while the Syrtis appeared as usual . . . it was as if a brownish screen had been drawn over all the region."

DIFFICULTIES OF LOWELL'S THEORY.—Lowell's theory is plausible, but there are some difficulties. Thus the polar cap must be very thin, from the rapidity with which it melts, and it is difficult to imagine that it could give enough water to irrigate the whole planet. Moreover, the water could not flow over the same regions from both the north and south poles, unless it were artificially helped by pumping operations. The theory really implies the presence of intelligent inhabitants who have carried out a vast scheme of irrigation. Another difficulty is to see how sufficient vapour could arise into the air to replenish the polar caps, for some water would be absorbed into the soil, and some would enter into chemical combination, and cease to exist as water. Such a process of desiccation is going on upon Earth, though its effects are not very noticeable. Mars may well be older than the Earth, in which case the desiccation would have advanced further. Hence, if we grant the intelligent inhabitants, the necessity for great irrigation works is quite reasonable.

CRAWFORD'S THEORY.—We now pass to the other extreme hypothesis, that the planet is a dead frozen world—a view which is embodied in a

paper by Mr. Robert Crawford. According to him, any water on the planet exists in the form of a mineral as hard as ironstone. The white deposits that cover large regions, such as Hellas, during the winter season, he supposes to be carbon dioxide, which would be precipitated at a temperature of about -100° C. at the low pressure prevailing there. He suggests that the polar caps may be frozen air, though he seems to overlook the effect of the very prolonged sunshine at the poles, rendered more intense by the slight absorption of the planet's atmosphere. He makes a novel suggestion for the canals, *i.e.* that they are lines of surface tension in low-lying mist. He has seen similar lines in the vapour over a warm liquid, and noted that the lines returned to the same position when blown aside, by some process that he compared to crystallization.

GREEN AND MOLESWORTH'S THEORY.—Another view of the canals is that they are the edges of regions of slightly different tone of shading. This was suggested by Mr. N. E. Green in 1879, and is probably true for some of them at least. Captain Molesworth says:

"I have come to the conclusion that in the great majority of cases the canals, especially the fainter ones, are the slightly darker borders of very faintly shaded areas. In some cases no true canal is visible, but simply the outline of a shaded area. But there is generally a distinct bounding streak darker than the area."

This view is shared by M. Antoniadi, who, however, shares Mr. Lowell's view of the "seas", and remarks:

"We can . . . consider the vast yellow expanses as being deserts; the dusky areas corresponding apparently to plains covered with water, and extensive tracts of vegetation, whose colour varies in fair accordance with the rigours of winter, the return of spring, or with the scorching radiance of a summer sun".

We may then take it as established that Mars illustrates planetary decrepitude.

CHAPTER V

THE MOON

A DEAD WORLD.—There is one more world to consider before we leave the solar system. This is the Moon, a world so near us that we can study her surface with an exactness impossible elsewhere. She is evidently a practically dead world; if any changes at all are in progress, they are on a very small scale. It is, indeed, doubtful whether the Moon has ever lived in the sense in which the Earth does now. She has been the scene of

tremendous activity, but of a volcanic kind, and has probably never been the abode of any organisms, either animal or vegetable, similar to those on Earth.

We shall see later that the Moon is probably the Earth's offspring, having been separated from it by solar tides at a time when this was still intensely hot, and rotated much more rapidly than now. Mr. S. A. Saunder gives strong reasons for thinking that the Moon would only carry away one seven-hundredth of the air (which at that time probably included the water in the form of vapour), and that even that small amount has been lost, either through absorption into the crust or by escape into space. He says that all geologists who have studied the Moon (Professors Becker and Shaler are especially mentioned) are confident that there is no sign of aqueous action:

"What were called the seas showed no sign of ever having been water, and the crevasses (rills) showed no signs of ever having been river beds. Anyone who studied the subject would notice the great sharpness of the ridges, the steepness of the slopes, the want of rounding of the hills."

Nevertheless the study of the Moon is interesting and profitable, as illustrating volcanic action far more potent than any now to be found on the Earth, but such as may have existed here in earlier times, of which the traces have been destroyed by denudation. Proctor seems to have been the first to suggest this, and his view has been extended by Professors Shaler and W. H. Pickering.

ABSENCE OF AIR PROVED.—Before commencing a description of the Moon's surface, it will be well to give the decisive proof that she is practically airless. This is based on the principle of refraction of light. It is found by measurement that when a heavenly body seems to be on our horizon it is really 34 minutes below it, the rays being bent through that angle by our air. If we imagine a ray just grazing the Earth's surface and then continuing its course out of the atmosphere, the total bending would be twice the amount, or 68 minutes. Now, when the Moon passes over a star, it disappears instantaneously, and the discussion of a large number of such occultations gives a very accurate value of the Moon's apparent diameter, for the effects of local irregularities would be smoothed out in the mean. Dr. Struve has deduced in this way the value $15' 32.65''$ for the semi-diameter. Now it will be noted that the ray from a star at the moment of occultation is just such a grazing ray as we imagined above, and if there is any refraction by a lunar atmosphere it will show its presence by the *occultation diameter* being notably smaller than that measured directly.

Mr. Cowell has deduced, from fifty years' observations of the moon at Greenwich, the value $15' 33.7''$ —about 1 second greater than Struve's value. Some of the excess is known to be due to *irradiation*, a physiological phenomenon which causes all bright objects to look slightly too large. The amount of refraction of a ray grazing the Moon's surface cannot exceed $\frac{1}{4}$ second, *i.e.* one-five-thousandth of the amount on Earth. This is barely distinguishable from that given by a perfect vacuum. Nevertheless, several most skilled observers have in recent years detected evident signs of mist or hoar frost in certain regions. These can scarcely indicate a continuous atmosphere, but are probably local discharges produced by the heat of the sun.

ROTATION SYNCHRONOUS WITH REVOLUTION.—One of the first things that we note in examining the Moon is that she always turns the same face to us; in other words, her rotation time is equal to her time of revolution. This exact coincidence cannot be accidental; indeed, there is no doubt that it was brought about by the tides raised by the Earth in past ages. These tides do not imply oceans; they may have been in the molten surface, or possibly bodily tides in the crust. The maintenance of the relation proves that the diameter pointing towards the Earth must be slightly longer than the others, but the difference is probably only a fraction of a mile. The polar flattening is insensible, which is a natural consequence of the very slow rotation.

Before proceeding to a description of the Moon's surface it is well to begin with a warning that even with the highest powers of the finest telescopes it is still at a naked-eye distance of about 150 miles, so that it is impossible to make out very minute details, such as the nature of the rocks; though, by taking advantage of the long shadows that accompany a low sun, it is possible to discern very slight inequalities of level.

THE MARIA.—Even with the naked eye we can plainly see a number of dusky markings on the disc. Galileo, who first applied the telescope to astronomy, gave to them the designation "Seas" (*Maria*), though it is doubtful whether he really imagined them to be water; at all events the increase of optical power quickly decided in the negative, since inequalities of a permanent character are visible upon them. The idea has, however, been entertained by many that they were the dried-up beds of ancient seas. They undoubtedly possess some features that do suggest this view. Thus we can frequently see ruined crater walls near their edges, and faint remains of old formations are traceable on their floors, as though covered by sedimentary matter. As a typical instance of the first we may mention Fracastorius, half of whose wall has been destroyed by an inundation of

some liquid matter; for the second we select two instances from a list prepared by Mr. W. Goodacre:

"Near Encke, on the border of Oceanus Procellarum, are the remains of four obscure ring plains. . . . An observation by Mr. C. F. Smith, 1898, Jan. 9, shows a number of oval light markings on the surface of Sinus Iridum, which gave a strong impression that they are the remains of once prominent ring plains, whose walls have been overwhelmed by the matter which forms the present surface."

THE BOLIDE THEORY.—It is not, however, necessary that water should have been the denuding agent; more probably it was liquid lava. The formation of the Maria cannot have been at a very early stage of the Moon's history, in consequence of their covering the ruins of so many prior formations. Professor Shaler, whose views as a geologist are particularly interesting, adopts the view (*bolide theory*) that they were made by the sudden descent of large meteoric masses on the surface, producing such a high temperature that it was immediately liquefied and reduced to a highly fluid state. He thus accounts for the peculiarities of the Maria—the general level of their surface, the destruction of formations on their floor, the onward sweep of the liquid till it reached some high barrier, which it often partially melted down before it came to rest.

If the lava flow came from the interior, as in an eruption, we should expect to find a steep edge to it, as in terrestrial lava flows, but none such can be detected. Shaler further points out that where there are depressions in the area on the border of the Mare the material flows into them, as a fluid would have done. All this points to greater fluidity than seems to have been the case in the lunar volcanic eruptions, and implies an external source.

OBJECTION TO BOLIDE THEORY.—The only difficulty about this bolide theory is that there are certainly no bodies of sufficient size (say 5 or 10 miles in diameter) now moving so as to meet the Earth or Moon. The nearest approach to them is Eros, perhaps some 20 miles across, coming within 14,000,000 miles of us. But the active epoch on the Moon carries us back to a very early stage in the history of the system, when there is good reason to think there were many such bodies, which have since then coalesced into the planets; such bolides may have also fallen on the Earth, but all traces of the fall have been obliterated by the various erosive agencies at work here, which do not exist on the Moon.

GROUPING OF THE MARIA.—There is one rather noteworthy feature about the grouping of the Maria—they seem to cluster towards the centre of the visible hemisphere. Mr. Maunder suggests from this that they have

been produced by some terrestrial tidal action. Professor Shaler agrees as to the fact, and considers that none of the *Maria* reach as far as the visible limb, so that the unseen region may have none of them. On his theory this would seem to imply that the mare-producing bolides were Earth-born. Many astronomers have thought it probable that in its early days the Earth may have expelled meteors, and that a large proportion of those that reach us are her own children; but it is doubtful whether any of these were large enough to have produced the *Maria*.

THE CRATER MOUNTAINS OR VULCANOIDS.—We pass now to the *crater mountains*, which are very numerous and of all sizes, from such mighty rings as Tycho and Copernicus, 50 miles in diameter, down to tiny pits less than a mile across. Professor Shaler groups them all under the name *vulcanoids*, meaning to imply their volcanic origin, and yet an essential difference from terrestrial volcanoes. This difference arises from the absence of water, which nearly all geologists agree to be an important factor in our eruptions, the explosive nature of which is due to infiltration of water, which is violently turned into steam by the high temperature within the Earth.

TERRACES OF CRATERS.—We should therefore expect less violent eruptions on the Moon, and a less energetic flow of lava, in consequence of diminished gravity. This cause would render the lunar lava more viscid, and diminish the tendency of imprisoned gases to escape from it. The successive terraces in the crater walls are supposed to arise from successive flows of this viscid lava, which could come to rest at a much higher slope than is possible here.

EVOLUTION OF VULCANOIDS.—Shaler thinks that the vulcanoids began as dome-shaped elevations, such as occur in numbers elsewhere on the surface. When distended beyond its strength such a dome would collapse, leaving a pit, the lava from which would produce the ramparts. At a later stage, when the activity was declining, the flow would not be vigorous enough to reach the rampart, but would form rude heaps in the centre of the ring—the “central cones” that are a characteristic feature of the great craters. There seems to be no evidence of any lava flows outside the craters of the vulcanoids, probably because the lava was too sluggish to break through any obstacle. The much higher fluidity of the *Maria* permitted their materials to invade neighbouring craters, notably Plato and Grimaldi, which share the dark colour of the *Maria* they adjoin, though no connection can now be traced.

LONG-CONTINUED VOLCANIC ACTION.—The period of volcanic activity must have lasted a long time, for we can clearly trace the signs

PART OF THE MOON

Reproduced by kind permission of the Director of Yerkes Observatory. Theophilus, Cyrillus, Catharina, are the three large craters near the centre, Theophilus being the lowest. It will be seen that its ring has invaded, and partially destroyed, that of Cyrillus; it also shows an unusually large central hill, and parallel terraces in the ring; Catharina shows clear evidence of successive outbursts. Some small pressure ridges are seen on the Mare Nectaris near the bottom of the plate.



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PART OF THE MOON, SHOWING THEOPHILUS, CYRILLUS, CATHARINA
PHOTOGRAPHED AT THE YERKES OBSERVATORY

of successive outbursts, one of the clearest cases of the kind being the pair of great craters Theophilus and Cyrillus. It is evident at once that Theophilus is newer, and that it has invaded and partially destroyed the older ring. The relative newness is shown by the greater sharpness of the terraces, those of Cyrillus having a worn and dilapidated appearance. It is to be noted that in spite of the absence of aqueous and atmospheric denudation there is undoubtedly an agency at work which might produce a gradual change in some of the details.

This is the great difference of temperature between day and night; the latter temperature must be very near the absolute zero (-273° C.), while that in the daytime is at least 250 degrees higher. In fact, Lord Rosse's measures made it as hot as boiling water, but those of Langley, which are probably more accurate, make it near the freezing-point. Such a wide range must cause considerable expansion and contraction, and might readily cause the fall of some steep slopes. The phenomenon known as "creeping" might also occur, which would cause the slopes to gradually work downwards.

PROBABLE CHANGES OF LINNÉ.—There is strong evidence for at least one change of the kind within recent times, *i.e.* in the crater Linné. Lohrmann says: "The second crater on the plain . . . with a diameter of somewhat more than one German mile, is very deep and can be seen in every illumination". Beer and Madler selected it as a point of the first order in their survey, and describe it as $1\frac{1}{2}$ German mile in diameter:

"Near the Full Moon it was a white spot, almost as white in the middle as at the edges. . . . The deepness must have been considerable, for I have found an interior shadow when the sun had an altitude of 30 degrees."

The first announcement of a change was made in 1866 by Schmidt, who says:

"I missed Linné, or rather its crater form, which at that time ought to have shown with especial distinctness and deeply shadowed".

Since then the appearance has been a whitish cloud, with faint ridges indicating a large ruined ring, and a very small crater within the oval. There would be no doubt of a change but for a rather vague description by Schröter in 1788, which seems to agree rather better with the modern aspect. Even Shaler, who is reluctant to admit any change in recent times, remarks:

"I am inclined to think that the case of Linné is the strongest, and that the walls of that vulcanoid may have . . . fallen into the original cavity, so as to leave only a small pit unfilled".

ASTRONOMY

The white spot round Linné is interesting as being one of the regions where Professor W. H. Pickering traces the deposit of hoar frost. He finds that the size of the spot varies regularly during the lunar day, and that it is also modified by eclipses, which seems to imply a temperature effect. He even suggests that certain variable dark spots near the places where the vapour is supposed to issue may be a low type of vegetation supported by these vapours; but this is extremely speculative.

CHANGES IN THE TWIN CRATERS MESSIER.—Another case of supposed variability is that of the twin craters Messier, which are said to undergo a cyclical change of shape in the course of a lunar day. It is not certain that the change is more than optical, but if real it may arise from the expansion and contraction of a great mass of rock so balanced as to be free to slide to and fro.

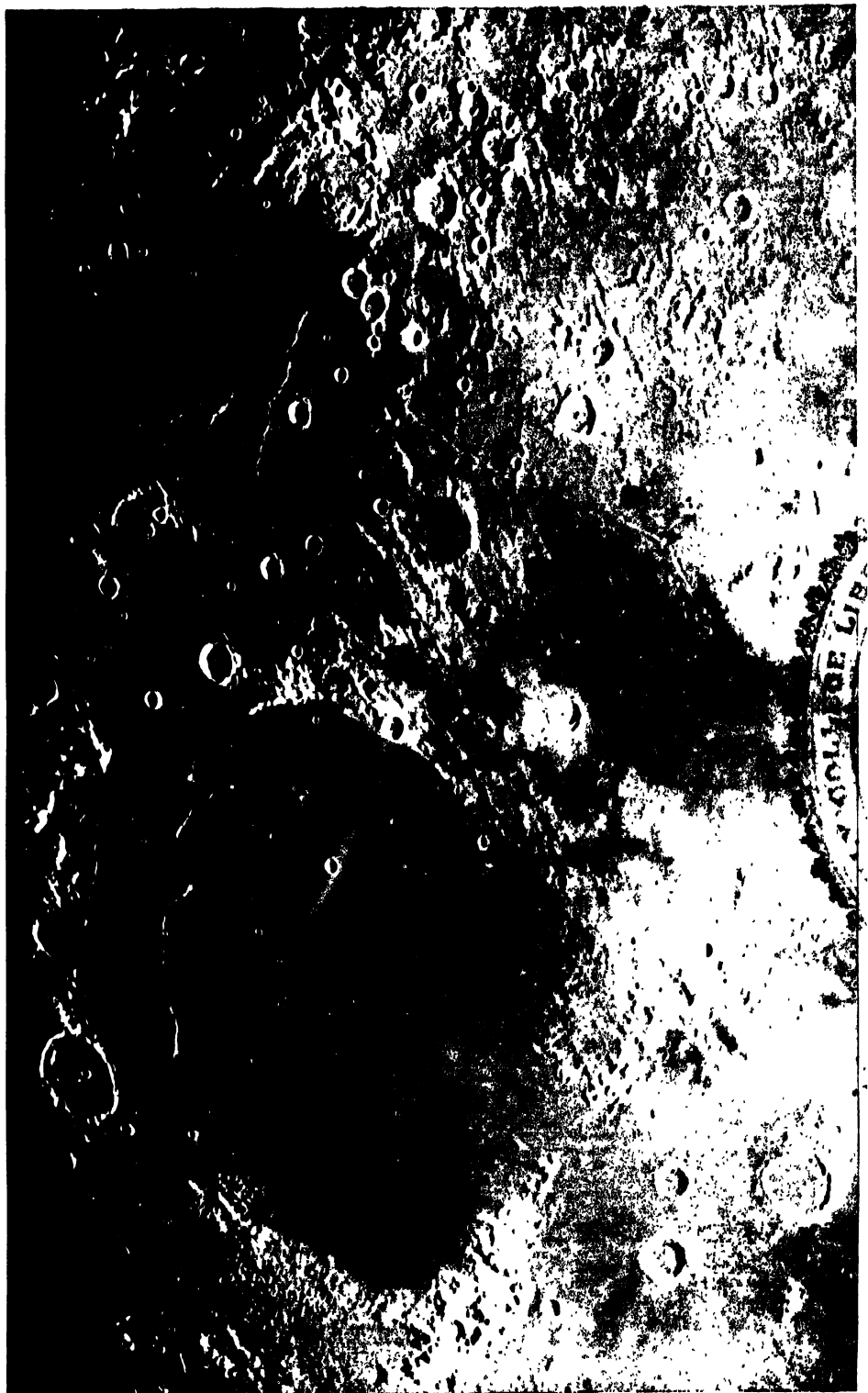
THE GREAT MOUNTAIN RANGES.—Besides the vulcanoids there are several continuous ranges on the Moon. Many of these are given terrestrial names from a supposed resemblance, which is not, however, borne out on a closer study. Thus we have the Alps, the Apennines, and the Caucasus. Professor Shaler classes these with the lumps of lava on the floors of the vulcanoids, concluding that they belong to a late period of eruptive activity, when the lava was too viscid to flow at all, but remained in great shapeless lumps just as it was extruded. They seem in some cases to have destroyed vulcanoids, showing their more recent date, while the few small vulcanoids to be found among them, such as Conon in the Apennines, may have arisen from a slight recrudescence of the earlier form of activity.

PRESSURE RIDGES AND FAULTS.—The only form of lunar mountain in which Shaler admits a terrestrial analogy are the long, low, curved ridges which occur on the floors of the Maria; these from their shape at once suggest that they are pressure ridges, caused by the cooling and contraction of the crust. This action in other cases led to faults and valleys, such as the Great Valley of the Alps. This is 80 miles long and about 4 miles wide, having very steep, nearly straight walls, exhibiting none of the rounding, scouring action that water produces in our valleys. The so-called *Rills* seem to be similar faults on a smaller scale; there is one notable case where the two sides of the fault differ 1000 ft. in altitude; this is the Straight Wall of Thebit, which runs in a straight line for more than 60 miles.

THE BRIGHT RAYS.—The contraction and cracking of the crust may also be responsible for the great systems of *Bright Rays*, the most perplexing of all the lunar features. These extend radially from a number of

THE MOON
REGION OF MARE SERENITATIS
AND THE APENNINES

The oval dark region low left on the Plate is the Mare Serenitatis; the winding ridge near its left-hand boundary is one of the best examples of the pressure ridges on the Maria, mentioned in the text as the nearest counterpart on the Moon to terrestrial mountain ranges. A little to the right of this a bright ray (one of the Tycho system of rays) will be seen crossing the Mare obliquely from top to bottom. There is a small crater where it enters and leaves the Mare, and others along its course, from which Professor Shaler concludes that these rays are probably caused by fractures along lines of weakness, and that the cracks may have taken place successively from crater to crater. The arrows at the right and bottom of the Plate point to Linné, which now appears only as a whitish cloud, but which was formerly described as one of the most conspicuous craters on the Mare; this is considered the best-established case of change on the Moon's surface in recent times. To the right of Linné, and running to the edge of the Plate, are the Apennines, the largest mountain range on the Moon. The slope on the upper (south) side is gradual, on the lower side very precipitous.



(7)

To
Linné

THE MOON. REGION OF MARE SERENITATIS AND THE APENNINES

centres, such as Tycho, Copernicus, Kepler, &c. Those of Tycho are far the most extensive, one ray going across the Mare Serenitatis and to the edge of the disc, a distance of 2000 miles. They run indifferently over hill and valley, mare or bright region, showing their late date, since if earlier than the other formations they could hardly fail to have been obliterated by them. It was long ago suggested that they bore a resemblance to cracks in glass or some similar material, through which vapours from the interior might have exuded, which condensed into crystals on the ground; and this idea, though modified in the details, still remains the best explanation. Professor Pickering has noted that the very long Rays are broken up into sections divided by craterlets, which he supposes to mark the limits of successive stages of the cooling and cracking process. The continuation of the previous crack would be a line of weakness, just as a split in wood is likely to extend itself in the same line. One feature of the Rays is that they are inconspicuous when the Moon is young, and gradually become more conspicuous as she waxes. This supports the crystalline nature of the formations, since the crystals would not reflect light equally in all directions, but in certain definite ones.

Mr. Tomkins has recently noticed deposits of salt in India which seem to present similar features on a smaller scale. M. Trouvelot observed that several of the Rills are continued beyond their extremities by thin white lines. This suggests that the vapours emerging were not sufficiently condensed where the Rill was wide to form a visible deposit, but could do so at their narrow extremities.

In the survey just given of the Moon's surface, Professor Shaler's theories have been closely followed, not as being the only tenable ones, but because they form a consistent whole, and are at least as probable as any other. They are, further, the work of an eminent geologist, and therefore inspire considerable confidence; indeed, there is only one point open to serious criticism, that is the invoking of external bodies (the supposed bolides) to account for the Maria.

There is one puzzling question raised by Professor Shaler, *i.e.* how is it that the fall of meteors on the Moon, which must be as dense as those falling on the Earth, has not covered all the markings with a veil and obliterated the differences of tint? It has, however, been calculated that even if the atmospheric density at the surface be only $\frac{1}{10,000}$ of that on Earth (a quantity which it may well exceed), then, since the rate of decrease is so much slower than on the Earth, at a height of something over 40 miles the densities of the atmospheres would be equal, and at still greater heights that of the Moon would be the denser. Now most of the meteors

that enter our air are completely burnt up at greater heights than this, so that the thin lunar atmosphere may actually be as effective for stopping meteors as our own. Of course most of the dust would in time settle down on the surface, but in such an impalpable form that it might be difficult to trace its presence.

CONCLUSION OF SURVEY OF SOLAR SYSTEM.—We have now completed our survey of the Solar System, in which our object has been to note those features which seemed to throw light on the manner of development of the different worlds. We have seen that they are at various stages of growth, from the Sun, which is still an infant in development, though doubtless the oldest of all in absolute age, through the giant planets, which are a few stages more advanced, to our own Earth in middle age, Mars, which is probably in decrepitude, and finally the Moon, which seems to be a dead world.

CHAPTER VI

THE STARS

OTHER SUNS THAN OURS.—It will be remembered that we made a comparison between the different worlds and the trees of a forest. To return to this figure, we may liken the Sun to a tree which has a number of shrubs and smaller plants growing around it, some just putting forth their leaves, others in full flower, others dying, and a few dead and withered. Now we shall suppose that in the distance we can see a number of other large trees, too far away for us to study in detail, or to see the smaller plants growing around them. Yet it will be profitable to examine them, for it is the only way in which we can hope to gain any experimental knowledge of the growth of large trees, since our time of observation is too limited for us to hope to see any change in the separate trees while we watch them, but we may expect to see specimens at various stages of growth, and possibly to detect different species, which pass through similar but not identical stages.

FIXED STARS AND NEBULÆ.—The Fixed Stars offer a close analogy to these distant trees, and we turn to them to see what light they can throw on the Sun's past and future. In the same region we shall find the Nebulæ, which seem to be inchoate systems at the very outset of their career.

THE UNIVERSE OF STARS.—The Solar System, huge as it is, is sur-

THE STARS

rounded by such a very much larger region of empty space that it seems small in comparison. It has been likened to an oasis 1 mile across in a desert twenty times the size of the Sahara. Beyond this great abyss lie the Fixed Stars, so called because the ancient observers could detect no change in their configuration. They, of course, noted the daily rotation of the star sphere and the precessional change, which causes the pole of rotation to slowly sweep out a circle in a period of about 25,000 years; but these were only caused by the Earth spinning and reeling like a mighty top, and did not involve any shifting of the stars *inter se*.

IMMENSE DISTANCE OF THE STARS.—The absence of such shift was felt to be a serious difficulty in accepting the Copernican doctrine that the Earth was revolving round the Sun, for it implied that the stars were at an almost inconceivable distance. As observing methods became more precise, constant efforts were made to detect such a shift, but these efforts, though rewarded by many interesting discoveries—such as aberration of light, nutation or the nodding motion of the Earth's axis, and the revolution of double stars,—long remained abortive in this special respect. To point out the full significance of their failure, it should be explained that the base available in this problem is not merely the diameter of the Earth, as it was in finding the Sun's distance. Once that distance was determined the diameter of her orbit became available, giving a base of 186,000,000 miles; yet even this huge base is as nothing compared with the stellar distances, and in only a few cases have we even now been successful.

THE NEAREST STARS.—Bessel was the first to touch bottom in the sounding of this ocean of space; he detected that the star 61 Cygni appeared to describe each year a tiny ellipse about $\frac{3}{4}$ second in length, implying that its distance is 500,000 times that of the sun, *i.e.* 47,000,000,000,000 miles, a distance of which we can form some conception by noting that light, which takes $8\frac{1}{4}$ minutes to travel from the sun, takes four hours from the outermost planet Neptune, but eight years from the star in the Swan! Such is the character of the interval between star and star. It has now been found that there are a few somewhat nearer to us, our nearest neighbour being Alpha Centauri (fig. 6), a bright star too far south to be visible

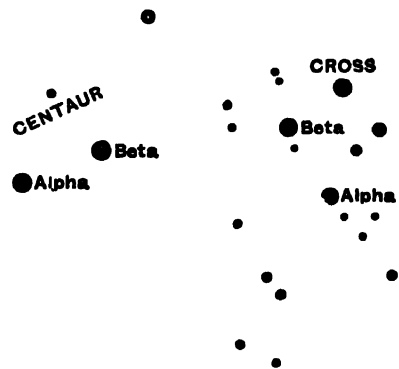


Fig. 6.—Diagram showing the Southern Cross and part of the Centaur. These stars are invisible in Europe. The two components of Alpha Centauri appear as one on the scale of this diagram.

in Europe, which is half the distance of 61 Cygni, or four years of light journey. At such gigantic distances it is obvious that the stars cannot shine like the planets, merely by reflecting the Sun's light. They are, in fact, the peers of the Sun, many of them greatly exceeding him in splendour, and perhaps forming the centres of still grander retinues of worlds.

THE NUMBER OF THE STARS.—The stars of heaven have for ages stood as the symbol of an innumerable host. The number visible to the naked eye at once is, however, smaller than is usually imagined, and seldom exceeds 2000. If we include the whole sphere, the number that can be seen by a normal eye is about 5000. The slightest increase of optical power greatly increases this number, and it is estimated that the number visible with our largest telescopes lies between 100,000,000 and 1,000,000,000. The problem of ascertaining their constitution and motions is thus a gigantic one, which we can never hope to accomplish in its entirety. Still there has been immense progress, more especially since the introduction of the camera and spectroscope, and discoveries have been made which would have been deemed impossible a century ago.

BRIGHTNESS AND COLOUR OF THE STARS.—The most casual inspection of the sky shows that "One star differs from another star in glory"; there is a difference both in brightness and in colour. The former may arise either from difference in the distance or in the real light power; we cannot say which, unless the distance has been measured. We are on safe ground in saying that fainter stars are on the average the more distant, but we cannot rely on this in individual cases, since there is known to be a very wide range of real lustre. The colour difference is independent of distance, and forms a most valuable criterion of the star's condition, and the stage of growth that it has reached. The spectroscope is here an invaluable aid, for it analyses that colour difference and shows how it arises.

STELLAR TYPES

HELIUM AND SIRIAN TYPE.—Stars have been divided into a number of types, according to the character of their spectra. Type I consists of bluish-white stars, of which the most conspicuous example is Sirius, the brightest of all the stars. Their spectrum is much simpler than that of the Sun, and evidently they possess atmospheres which have but little absorptive power, with the exception of the absorption lines of hydrogen, which are marked with extraordinary distinctness. Owing to the slight absorption the spectrum can be studied far down beyond the violet, and a series of hydrogen lines has been found here, making with those in the

VARIOUS SPECTRA

This plate (kindly drawn for this work by E. M. Argyræad) shows the various types of spectra to which reference has been made.

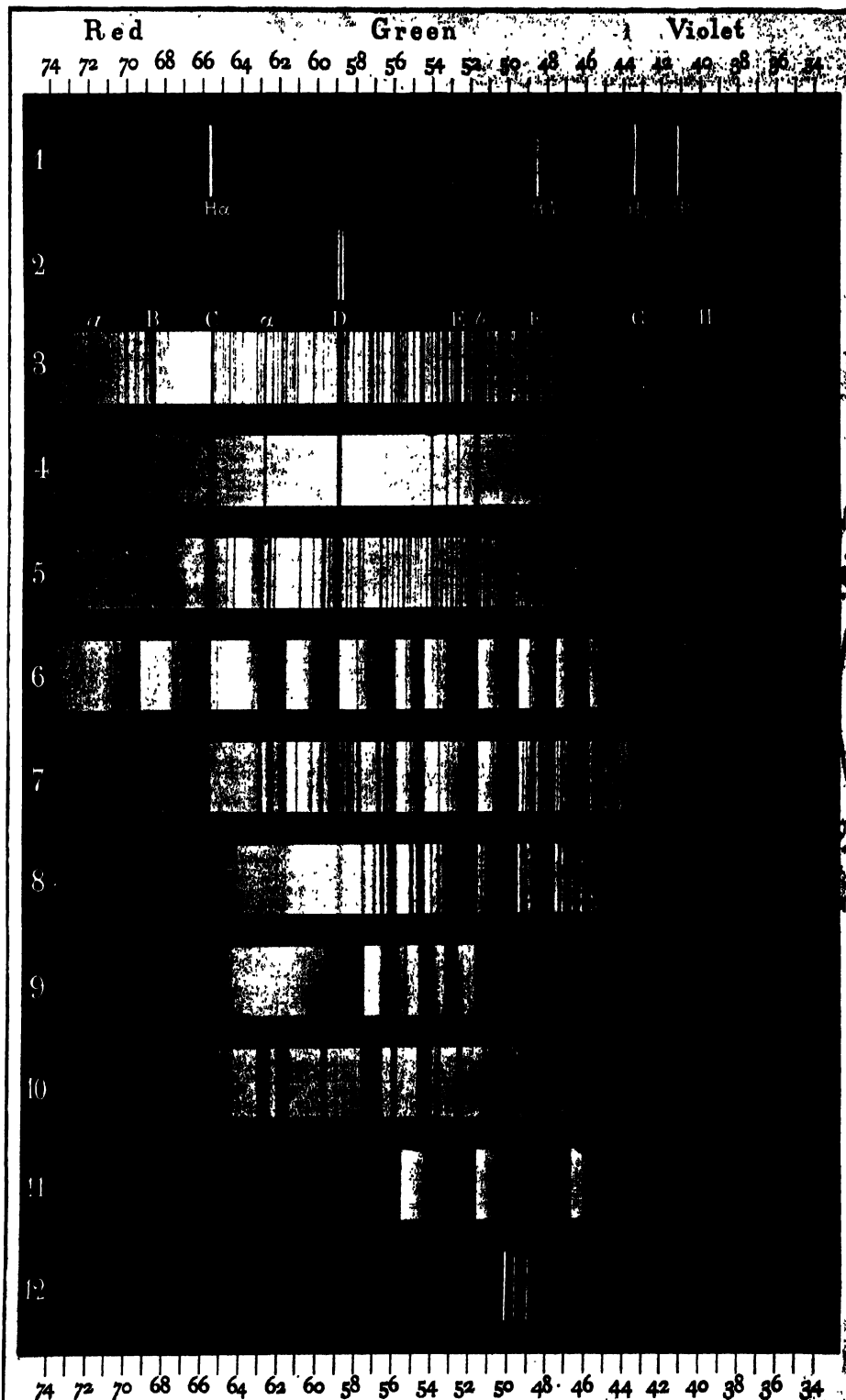
1. The principal lines in the spectrum of glowing Hydrogen. The first three of these lines are the C, F, G lines in the Sun's spectrum.

2. The brilliant double line in the yellow given by glowing Sodium. This is the D line in the Sun's spectrum.

3. The Solar spectrum. The heavy lines marked H are due to Calcium; these are the lines generally used with the spectro-heliograph for obtaining the Florenti.

4. The spectrum of light from the hydrogen light source, which is a source of light of the same nature as the light from the Sun.





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VARIOUS SPECTRA

DRAWN BY E. M. ANTONIADI

visible spectrum a remarkable rhythmic series. The helium stars form a sub-class of Type I; they show plainly the lines of the gas helium, long known to exist in the Sun's surroundings, but only lately found on Earth. The fact that this gas is one of the emanations of radium makes its presence in the stars of special significance, for it may be the source of some of their immense stores of energy. Professor Newcomb, in his *The Stars, a Study of the Universe*, gave a remarkable prediction of the discovery of the radio-active substances:

"What we see must therefore suggest at least the possibility that all shining heavenly bodies have connected with them some source of energy of which science can as yet render no account. Facts are accumulating which converge to the view that forms of substance exist which are neither matter nor ether, . . . in which is stored an almost exhaustless supply of energy."

SOLAR TYPE.—Stars of the second type have a golden tinge; to this our own Sun belongs, so it is sometimes known as the *solar type*. The golden hue is due to a smoke veil, or obstructing layer in their atmosphere, which absorbs much of the violet light. It follows that since more of the light of solar stars is stopped by their surroundings, if a sirian and solar star appear to us equally luminous the latter is likely to be more massive (the distances being supposed equal). This is confirmed in the case of those stars whose mass we can find by the presence of a companion revolving round them. Thus Sirius is about eighty-three times as bright as our Sun would appear at the same distance, but only twice as heavy; while Alpha Centauri seems to be like our Sun in all respects—spectrum, size, mass, and density. Arcturus and Aldebaran are examples of Type II, but the spectrum of the latter is modified by the great absorption at the violet end, which gives the star its decided red colour; it appears in consequence much fainter in photographs than to the eye.

RED STARS OF THIRD TYPE.—We now come to red stars proper, which are divided into two classes. Both have banded spectra, but the bands are of different characters. The third type are sometimes called after Antares, their principal member. They resemble Type II in having many metallic lines, those of calcium, iron, sodium, and magnesium being conspicuous; but superposed on these are a series of dark bands, with sharp edges towards the violet, and shading off gradually in the other direction. Professor Fowler found in 1904 that most of these were due to oxide of titanium. Many of the Type III stars are variable, and it is probable that they are nearing the end of their career as suns and that their fires are beginning to flicker.

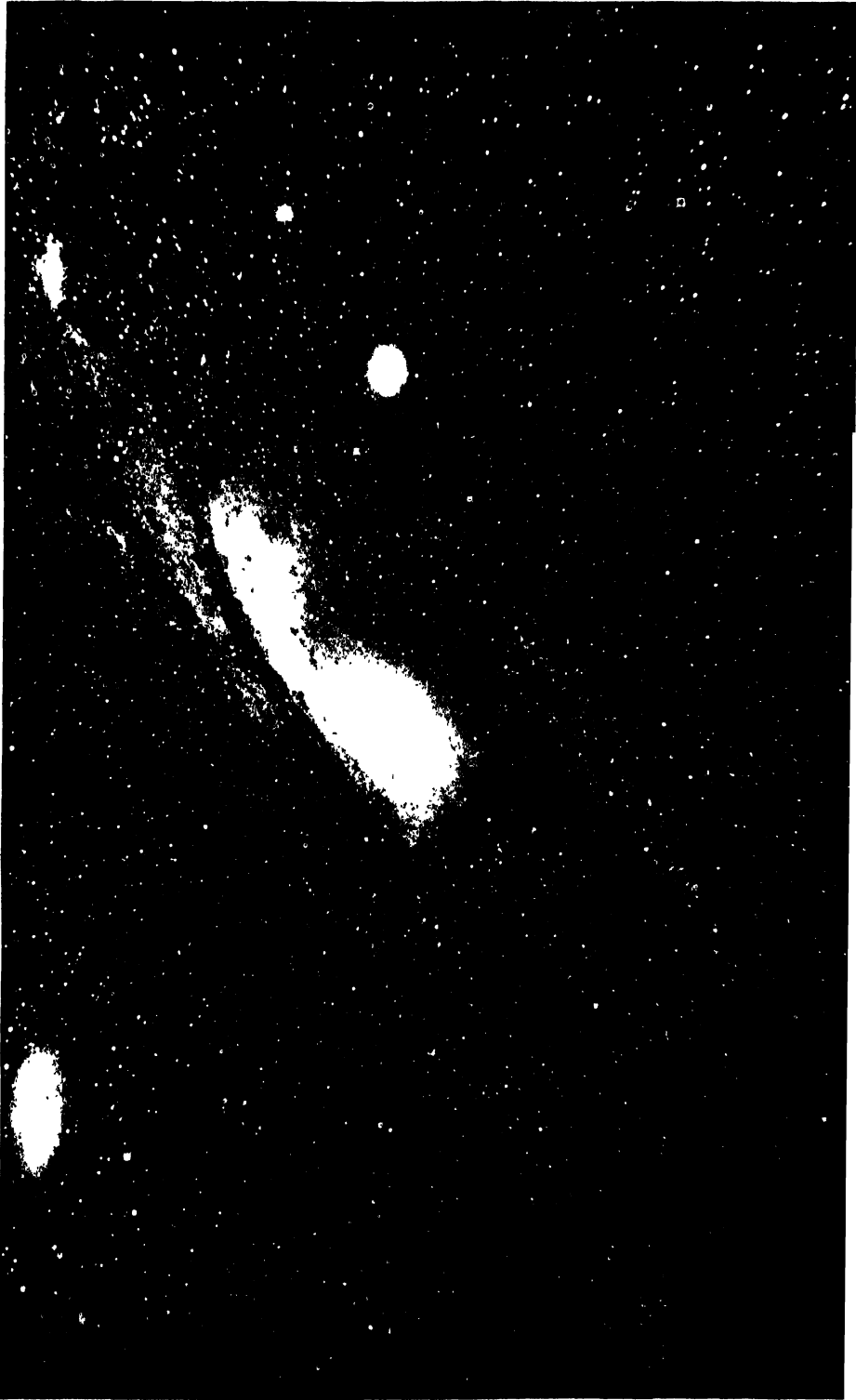
RED STARS OF FOURTH TYPE.—The stars of Type IV are intensely red, and all faint. Their spectra are likewise banded, but the gradation of the bands is in the other direction, being sharp at the red end. These bands are due to carbon and cyanogen; the spectra also contain some bright lines, indicating the presence of some intensely glowing gases in their atmospheres. Professor Hale thought that Types III and IV were two alternative routes along which stars might pass to extinction, but Miss A. Clerke gives a good reason against this view, *i.e.* that Type IV stars are not scattered uniformly over the sky, but are strongly condensed towards the "Milky Way", a region which we have reason to think is very remote. This seems to show that the stars of that region end their career as suns in a different manner from orbs in our neighbourhood.

FIFTH AND SIXTH TYPES.—Types V and VI seem to consist of stars at a very early stage of their career that are still largely gaseous. This is shown by their spectra containing vivid bright lines superposed on the continuous spectrum. In Type V the lines brightened are chiefly those of hydrogen and helium, and the brightness is subject to capricious changes, the cause of which is unknown. Type VI, like IV, is confined to the Milky Way, thus again implying that stars in that region of space are differently constituted from our neighbours. Stars of this type show some bright lines in the blue and yellow, one being identified with hydrogen by its relation to the rhythmic series, though terrestrial experiments fail to show it, so that it indicates some conditions unknown on Earth. Mr. M'Clean detected the lines of oxygen in Gamma Velorum, the brightest star of this type. It is curious that this gas, so common on Earth, very rarely leaves its traces on celestial spectra; a trace of it is, however, found in the solar spectrum. No metallic lines are seen in Type VI spectra, which probably denotes a very early stage of development.

NEBULÆ

NEBULÆ WITH CENTRAL STAR.—We now come to the class of Nebulæ, which in its turn has many subdivisions. There are some small round bright nebulae that seem almost stellar, with a star in the centre. It was the discovery of one of these in Taurus that led Sir W. Herschel to the idea that a shining fluid exists in space. Science abandoned this view for a time in favour of the idea that the nebulae were all clusters too remote for the separate stars to be seen. Herschel's view, however, has been demonstrated by the spectroscope.

PLANETARY NEBULÆ.—These make up a second class, and have been



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THE GREAT NEBULA IN ANDROMEDA

PHOTOGRAPHED AT THE YERKES OBSERVATORY

It was one of them that Sir W. Huggins first tested spectroscopically, finding the bright-line spectrum of glowing gas; the most conspicuous line is in the green, from an unknown gas which has been named *nebulium*. Other classes are *ring*, *spiral*, *double*, and *irregular* nebulae.

SPIRAL NEBULÆ.—These constitute an especially important class. Before the camera was applied, one specimen was known, the Great Spiral in Canes Venatici. Photography revealed the true structure of the Andromeda Nebula, showing that it was a magnificent spiral seen obliquely. Since then photographs taken with the Crossley reflector at Mount Hamilton show that spirals are to be counted by the thousand, and we seem to see in them the actual process of formation of worlds and systems. It would appear that the original hypothesis of Laplace, of a great nebulous sphere shedding successive rings, must be abandoned. We see an immense flat disc split up into concentric whorls, some of which have already separated from their parent, and appear as independent nebulae, a process which we may presume will continue till the whole is thus distributed into planets like the solar system on a grander scale. For our system, at the distance of the nebulae, would appear as an insignificant point, while some of them are of great apparent size.

IRREGULAR NEBULÆ.—The status of these is doubtful. They assume all manners of fantastic forms, and in many cases have received names to match, thus we have The Crab, The Owl, The Dumb-bell, The Keyhole, The America (which bears a strong resemblance to the map of North America), and The Spindle. The most remarkable of all, the Great Nebula in Orion, has a portion known as the "Fish's Mouth", a curious dark indentation containing a trapezium of stars, whose connection with the nebula is supposed to be real, not merely optical. Even with slight optical means the splendour of this nebula is evident, but the camera has extended it enormously. Professors Pickering and Barnard have obtained photographs showing "An enormous curved nebulosity encircling the belt and the great nebula, and covering a large portion of the body of the Giant". In comparison with this the old trapezium nebula "is but a pygmy".

IMMENSE SIZE OF THE ORION NEBULA.—Professor Pickering conjectures that the Orion nebula is 1000 light-years distant from us, in which case the diameter of this stupendous whorl is some 240 light-years, a magnitude too great for the mind to grasp. It is difficult to imagine that the central nebula can have sufficient mass to control the outliers at this huge distance, so that the object is probably undergoing disintegration.

The central portion has a complicated filamentary structure, showing that energetic processes are at work, but we can form no conception of what their outcome will be. From the character of the spectrum Dr. Scheiner deduces that both the density and the temperature are exceedingly small; the luminous glow may indicate electrical action.

That shining is not a necessary attribute of nebulae was shown by the nebula round Nova Persei in 1901. This expanded so rapidly that it evidently could not be an actual motion of matter, but probably successive regions of the nebula (which already existed in a dark condition) were made to glow as the radiations of the outburst reached them, dying out again when it had passed. Another indication of dark nebulosity is perhaps shown by the lanes void of stars which are seen near many nebulae. These may indicate non-luminous matter, which is, however, capable of stopping light. We cannot tell whether all nebulae will be transformed into systems of worlds, or whether only a small portion of them are destined for this end. In the case of many of the irregular ones it is at least difficult to see any traces of a tendency in this direction.

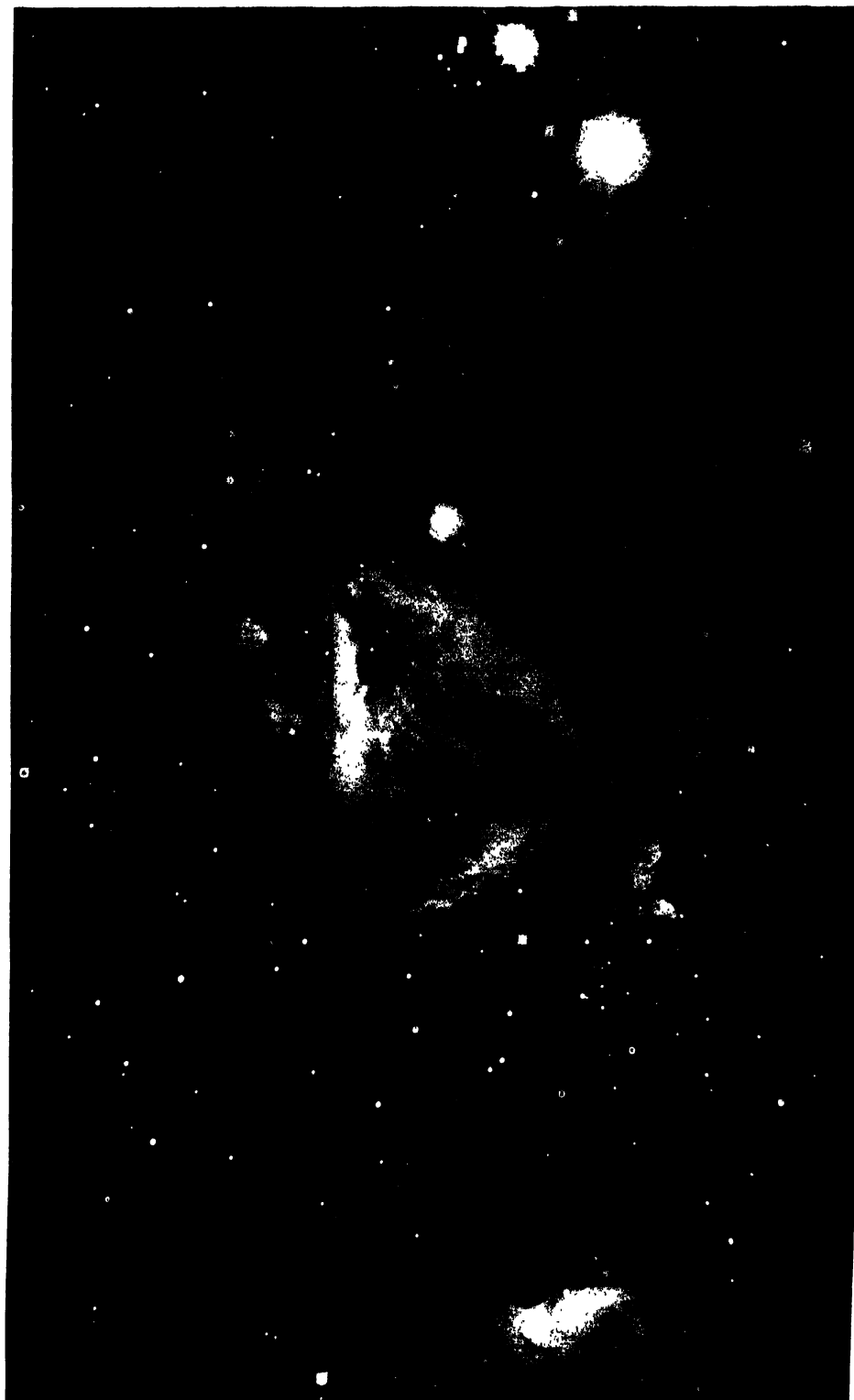
DISTANCES AND MOTIONS OF THE STARS

SLOWNESS OF MOVEMENT.—We now know that the designation “Fixed Stars” is not strictly applicable, but the motions of these bodies are so slow that they can only be detected by refined observations. We now possess accurate observations covering 150 years, beginning with Bradley’s work at Greenwich, and the motion of some stars in this interval is considerable. For example, Arcturus moves $2\frac{1}{4}$ seconds a year, and has moved $1\frac{1}{2}$ degree since the time of Hipparchus, so that were he to view the heavens now he might detect the shift even with the naked eye. A few stars have more rapid motions; the quickest yet known is an eighth-magnitude southern star, which moves at four times the pace of Arcturus. These, however, are exceptional cases, and generally a century must elapse before a distinct shift can be detected.

USE OF SPECTROSCOPE.—These motions help us to form an idea of stellar distances. As a rule the more rapidly moving stars are the nearer; but this cannot be pressed too much, for the real rate of motion varies greatly. Of late years a new and powerful method has been used, *i.e.* that of applying the spectroscope to examine the rate of approach or recession of stars by the shift of the lines of some known substance in their spectrum compared with that of the same substance on Earth. The value of the method is that it is independent of the distance of the object. Naturally

THE GREAT NEBULA IN ORION

Reproduced by kind permission of the Director of the Yerkes Observatory. Shows the immense size, complicated form and curious tree-like structure of this astonishing object.



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THE GREAT NEBULA IN ORION
PHOTOGRAPHED AT THE YENKES OBSERVATORY

THE STARS

attempts have been made to explain the stellar ones, by revolution round some central body; and it was for a time thought that Madler had found the centre in the group of the Pleiade. But the idea has not stood the test of time, and it is now recognized that the plan of the stellar motions is less simple than this. It is not even certain that the universe of visible stars is destined to keep permanently together. A few stars in it, notably Arcturus, have speeds of several hundred miles per second, which is probably too great for the other stars to control.

MOTION OF THE SUN—STAR DRIFTS.—Another quest of astronomers has been to find the direction and rate of the Sun's motion. We may note that this can only be done on the assumption that the group of stars employed for the purpose has no tendency to drift in one direction rather than another (in other words, that its centre of gravity is at rest). On this assumption Sir W. Herschel found that the sun is moving towards a point in Hercules, and many more recent computers have deduced a point in the same direction, but with decided differences according to the group of stars selected, showing that the initial assumption is not quite justified. During 1906 Professor Kapteyn and Mr. Eddington have shown that the stars around us belong to two drifts, each of which has a general tendency to drift in a certain direction, though the individual stars have motions special to themselves in addition to this.

The sun appears to belong to Drift II, which is mainly composed of stars with the solar type of spectrum, and in consequence the relative motion of Drift II is smaller. There are many instances of groups of stars travelling in company; thus, five out of the seven stars in the "Plough" or "Great Bear" are found to be fellow travellers, so that they have a real connection, not a merely optical one. The other two have an entirely different motion, so that in the course of thousands of years the group will quite change its appearance. Attempts have been made to find stars drifting in company with our Sun, but hitherto none have been found with rate and direction of motion near enough to his to show a close connection. If such stars exist, they would seem to have no proper motion, but a large annual parallax (as the shift produced by the Earth's motion is termed).

EXTENT AND SHAPE OF OUR STAR-CLUSTER (THE UNIVERSE)

GROUPING OF STARS IN RELATION TO MILKY WAY.—Proceeding to the question of the size and shape of the group of stars that fall within our ken, which we call the Universe, many computers have deduced that

the star density gradually increases as we pass from the poles of the Milky Way up to this zone. This is the case with bright and faint stars alike, and the inference is clear that this is not a small structure in our immediate neighbourhood, but the framework on which the whole visible universe is built. Counting stars of magnitude $9\frac{1}{2}$ and brighter, there are three per square degree at the poles of the Milky Way, and the number increases steadily up to $6\frac{1}{2}$ in this belt. The Herschels made similar counts, including much fainter stars, and found 100 per square degree in the first regions, 2000 per square degree in the Milky Way.

It is probable from this that the crowding in this belt is not merely a perspective effect, but that space in that region is actually much more crowded with stars. This is confirmed by the phenomena of New Stars, which appear without exception in the Milky Way or its outliers. It is generally agreed that these are due to some form of collision, and as stars in our neighbourhood are altogether too thinly strewn to give a sufficient number of such collisions, we again arrive at the conclusion that the region of space in question is much more densely populated.

DR. A. R. WALLACE'S THEORY.—It will be remembered that in 1903 Dr. A. R. Wallace published an article suggesting that the Earth was the only planet in our system, and our system the only one in the universe, suitable for the abode of intelligent inhabitants. The first point may be granted as not unlikely. As regards the second, it may be that the greater crowding of the Milky Way region, the different types of spectrum that prevail there, and the collisions that seem to occur pretty frequently, indicate that the orbs there present have a different part to play in the scheme of creation from our own Sun. But to say that the central situation of the latter is unique is quite unwarranted by the evidence; we do not know that it is in the exact centre, only that it is towards the "Midland Regions". There are thousands of other stars with an equal claim to centrality, and many of these seem from their spectra to closely resemble our Sun. In short, while the evidence justifies us in saying that the conditions for habitability by higher forms of life are somewhat exceptional, it by no means justifies us in asserting that they are only present on this one world in the universe.

STAR DENSITY OF THE UNIVERSE.—Professor Newcomb has endeavoured to determine the star density in our region of space by a discussion both of the parallaxes and proper motions. His conclusion is that there is, on the average, but one star in a volume equal to that of a sphere whose radius is 400,000 times the Earth's distance from the sun. A radius 500 times this, or about 3000 light-years, would contain 125,000,000 stars,

which is probably as many as our best instruments would show, excluding the Milky Way. Hence the confines of our universe, except in the Milky Way direction, may not be more remote than this. The Milky Way itself is probably still more distant, and Professor Newcomb gives reasons for concluding that none of the stars in it have any sensible proper motions; in other words, the stars which have a sensible motion are distributed uniformly round us, and show no tendency to concentration in the Milky Way zone.

BRIGHTNESS AND MASS OF STARS.—Some of the bright stars in this zone have no sensible parallax or proper motion, hence they are supposed to be at the distance of the Milky Way, and their brightness must be thousands of times the Sun's. Among them are Rigel, Canopus, and Alpha Cygni. At the other extreme there are some faint telescopic stars with large parallaxes, whose brightness must be only about one-hundredth of our Sun's, so that stars differ among themselves in brightness quite as much as planets do. Probably the range in mass is not quite so great as in brightness, as in the case of Sirius; yet it must be considerable. Surprising as it may appear, it is possible to find the masses of many of the stars, *i.e.* the double stars, which are so important that a section is devoted to them.

DOUBLE STARS

CLASSES OF DOUBLE STARS.—When it was first realized that the stars were suns, it was assumed that they were in all respects analogous to ours. Hence, when many were found to be double, it was thought that the duplicity was merely optical, one lying far behind the other. Sir W. Herschel's measures proved, however, that many of these pairs were in visible orbital motion. This opened out a new conception, and showed that our type of system, with one absolute monarch, was not the only one, perhaps not even the commonest one, for double stars are now numbered by thousands. They are divided into the two classes of *visual* and *spectroscopic*.

SPECTROSCOPIC DOUBLE STARS.—These have been discovered by the character of their spectra. The lines in some cases double periodically, in others show a periodic rhythmic shift. This can be completely explained in each case on the hypothesis that we have here a pair of stars so close together that they cannot be seen separately. In the first case both are bright, in the second case one is obscure, but still sufficiently massive to cause the brighter one to move in an orbit, and to

alter its speed of approach to, or recession from, our system, thus producing the shift in the spectral lines.

Some pairs have nearly equal components, such as Alpha Centauri, Castor, and Gamma Virginis. Others, like Sirius and Procyon, differ enormously in brightness, but not so much in mass. Some pairs are so wide, and the stars so bright, that they can be seen double with very slight optical means, others tax our powers to the utmost.

PERIODS OF REVOLUTION.—The periods of revolution vary from a few days (in the case of spectroscopic doubles) to five and a half years, that of the shortest visual double (Delta Equulei), some 350 years for Castor, some 800 for δ Cygni, and doubtless thousands of years for others. To find the orbits, the observed positions are plotted in diagrams and an ellipse drawn through them. This gives the *apparent orbit*, which is a foreshortening of the *true orbit*. To find the latter we assume that the laws of gravitation apply to these systems. This is not absolutely proved by the observations, but it is rendered a moral certainty.

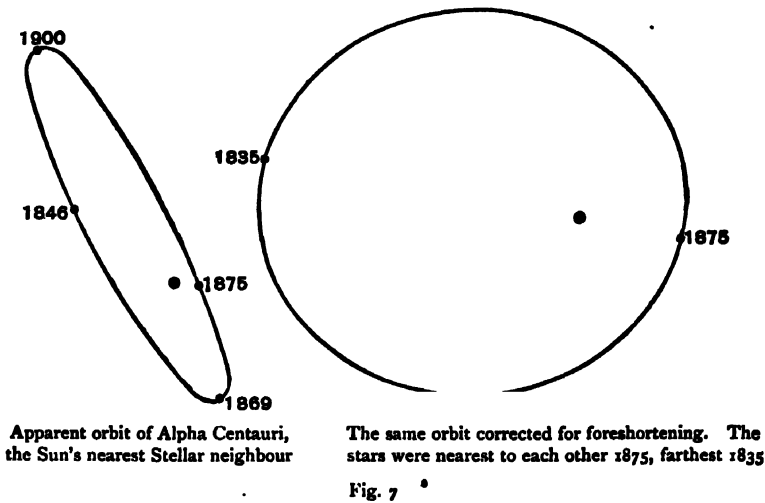
ECCENTRICITY OF ORBITS.—One striking feature of the resulting orbits was first pointed out by Dr. See, *i.e.* that the eccentricity is much higher than in the planetary orbits. The latter have an average eccentricity of one-seventeenth, while that for the former is about one-half, or eight times the other. This cannot be an accident, and Dr. See is doubtless correct in ascribing it to tidal action. This would be very great in the case of two large orbs revolving almost in contact, and it has been proved that one of its effects would be to increase the eccentricity. The tidal effects in our system are much less potent, though even here they seem to have played an important part, notably in connection with the separation of the Moon from the Earth.

EVOLUTION OF DOUBLE STARS.—We have already alluded to double nebulae, and it is probable that some double stars may have been formed in this way; but in the case of the very close pairs, especially those revealed by the spectroscope, it is probable that the separation took place at a later epoch. The different forms which a rotating mass of fluid can assume under its own attraction have been studied by M. Poincaré. At first, when the density is small, the shape will be a spheroid, like Jupiter; then the flattening will increase, and at a certain stage an equatorial protuberance will be developed:

“The larger part of the matter tends to approach the spherical form, whilst the smaller part projects from the ellipsoid at one of the extremities of the longer axis, as though it were trying to detach itself from the larger part of

the mass. It is difficult to state with certainty what will happen then if the cooling continues, but one may suppose that the mass will go on deepening its furrow more and more, and then it will at last divide itself into two separate bodies by the throttling of the middle part."

There is reason to think that some of the short-period variables exhibit the state of things that arises after a separation of this kind, *i.e.* two egg-shaped bodies, revolving almost in contact, with the pointed ends of the eggs adjacent to each other. As they revolve they sometimes present to us the figure of a pair of spectacles, at other times that of a single round orb. Beta Lyræ is the best example, and R² Centauri is



probably another. Tidal action will cause them to slowly separate, and will also make the orbit elliptical. It is quite possible that some of the variations of light in these cases may be due to the surging tides of fire sweeping over their surfaces, and causing their luminosity to change.

DOUBLE-STAR SYSTEMS AND LIFE.—It is quite unlikely that systems ruled by two or more suns can possess the stability necessary for planets supporting higher forms of life. Dr. See says of possible planets belonging to such systems:

"If planetary bodies revolved round either component they would experience great perturbations, besides the most violent changes of light and heat. It seems probable that planets could not be formed without developing very eccentric orbits, and if once in existence it is questionable whether such bodies could endure under the violent perturbations to which they would be subjected at periastron passage."

SYSTEM OF ALPHA CENTAURI (fig. 7).—It may be of interest to describe in detail one or two binary systems, taking first our nearest neighbour, Alpha Centauri. This consists of two suns, each very similar to ours in size, mass, brightness, and colour. The eccentricity of their orbit is one-half; the average, least, and greatest distance between them being respectively $23\frac{1}{2}$, 11, and 36 times that of the Earth from the Sun. In other words, when nearest they are slightly farther apart than Saturn from the Sun, when most remote the distance between them exceeds Neptune's distance from the Sun. We see the orbit foreshortened, the least apparent distance being $1\frac{1}{2}$ second, the greatest 22 seconds. The period is eighty-one years, and they have now been accurately observed for a whole revolution.

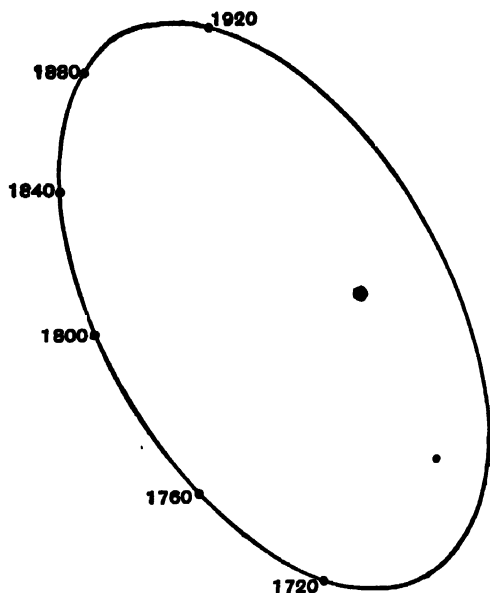


Fig. 8.—Apparent orbit of the Double Star Castor (after Lewis). Period about 310 years

SYSTEM OF CASTOR (fig. 8).—Another very interesting system is that of Castor, consisting of two bright stars (of second and third magnitudes) which a small telescope will separate. The period is long, probably about 350 years, of which only one-half has yet been observed. In the last few years each star has been found to be a spectroscopic binary, with a non-luminous companion. These companions were discovered by Drs. Belopolsky and Curtis. The periods of the two members of each binary are about nine days and three days, the fainter star being thus some

six times as massive as the bright, a relation which Mr. Lewis has found to exist in so many pairs that it seems almost to be established as a general rule. This is quite contrary to expectation, for we should expect the more massive orb to cool more slowly, and so to be brighter, but no clue has yet been arrived at to explain the anomaly. We can only roughly guess the distance of Castor. Dr. Curtis puts it at sixty-five light-years, which makes the total mass of the four orbs thirteen times the Sun's; but the light of the bright pair would be 100 times his, so they would be relatively much more luminous, which is in accordance with their Sirian type of spectrum.

STAR CLUSTERS

THE PLEIADES.—We are led up through multiple stars to *star clusters*, where hundreds or thousands of stars are congregated together, evidently in physical connection, though the nature of their movements is quite unknown. Some are visible to the naked eye, the Pleiades and Praesepe being well-known examples. The former group seems to be at an early stage of development, the principal stars being surrounded by nebulous appendages. Miss A. Clerke conjectures that this cluster is 190 light-years from us, in which case some sixty of the group surpass the sun in splendour, the leader Alcyone no less than 170 times. The diameter of the cluster would be five light-years.

GLOBULAR CLUSTERS.—There are many crowded globular clusters, and these are surrounded by long, curved star streams. These, as Miss Clerke notes, show the advance of change, either new stars being drawn in from outer space, or "full-grown orbs being driven from the nursery of suns in which they were reared, to seek their separate fortunes". It is quite possible that some of the clusters may really consist of very minute stars, in which case they would be analogous to the zone of minor planets in our system. We are wholly ignorant of the conditions according to which in one case a single large orb, in another a multitude of small ones, is formed, nor do we know the destiny of the latter, nor how equilibrium is maintained in these clusters. Sir J. Herschel indicated a way by which stars uniformly distributed in a spherical cluster might all move in ellipses in the same period, but these conditions do not seem to be realized in the visible clusters.

VARIABLE STARS

THE ALGOL TYPE.—We have already made allusion to these wonderful objects which undergo periodic fluctuations in their light. They are divided into those of long and short periods, and the latter are divided into those where the variation arises from eclipse, and those where there is a true fluctuation of light. Algol, or Beta Persei, is the principal example of eclipse variables, and gives its name to the class. Stars of this type are at their normal light the greater part of the time, but suffer a rapid temporary decline. It was conjectured that this was due to eclipse by a dark body very close to its primary, and coming between us and it in each revolution.

This idea was first suggested by Goodricke in 1783, and was confirmed a century later by Dr. Vogel with the spectroscope. He found

that, besides its average approach of $2\frac{1}{2}$ miles per second, it has an orbital motion of $26\frac{1}{2}$ miles per second, receding before minimum, approaching after it. Combining this with the duration of eclipse, he found the following elements of the system: Period, 68 h. 48 m. 55. s.; diameters of bright and dark stars, 1,060,000 and 830,000 miles; distance between centres, 3,230,000 miles; masses, $\frac{1}{4}$ and $\frac{3}{8}$ of Sun's. The smaller body is not necessarily quite dark, but its light cannot exceed 1 per cent of the larger's, or there would be a secondary minimum when it passed behind the latter.

The constancy of Algol's light during the uneclipsed period seems to show that it cannot differ much from a spherical form, which is contrary to expectation in the case of two large orbs almost in contact. We have already described the Beta Lyræ type, where the variation is not caused by eclipse, but by the different presentation of egg-shaped bodies. Another type of variable has been found in great numbers in the star clusters. Their period is generally less than a day, the minimum prolonged, and the rise to maximum extraordinarily rapid. No explanation of this type has yet been found.

THE MIRA TYPE.—Long-period variables seem to form a separate class, since there are hardly any with periods between 30 and 100 days, after which the curve runs up rapidly, showing a strong maximum at the value 330 days; it then falls fairly rapidly to 510 days, above which very few periods are known. While "Algol" stars are generally white, of the Sirian type, long-period variables are red, with third-type spectra; the most wonderful star of the class is appropriately termed *Mira Ceti*. Miss A. Clerke thus describes it:—

"Once in eleven months the star mounts up in about 125 days from below the ninth to near the third or even the second magnitude; then, after a pause of two or three weeks, drops again to its former low level in one and a half times, on an average, the duration of its rise. . . . An extent of eight magnitudes may be assigned to the oscillations of this strange object, which accordingly emits at certain times fully 1500 times as much light as at others. That each maximum is a genuine conflagration has been proved by spectroscopic observation; the conflagrations recur yearly, and, after three centuries of notified activity, give no signs of exhaustion!"

At maximum there is a striking outburst of bright hydrogen lines, while the titanium flutings are very clearly marked. This is the most striking example of a very numerous class. The fact that the periods of so many of these stars are about a year is curious, and suggests that the light variations may be due to a parallactic shift behind some opaque

screen, such as a nebula. In this case, however, the period would be exactly a year, and it also requires such an artificial arrangement that the explanation is not tenable.

ANALOGY WITH SUN-SPOT CURVE.—Sir Norman Lockyer suggested that stars of this type were double swarms of meteors, revolving in elliptical orbits, and approaching at periastron sufficiently near for the outer members to collide. This may be the true explanation in some cases, but it is on the whole more probable that the seat of variation is within the star, and that we have an analogy in the Sun-spot cycle. It has long been recognized that their light curves were similar to the Sun-spot curve. Professor Turner has established this by harmonically analysing the curves. He finds the Sun-spot maximum corresponds to light maximum in the stars. It is necessary then to suppose that more light is gained by gaseous outbursts than is lost by the spots. The Sun is only an incipient variable, and its changes would have to be accentuated before they could be detected at stellar distances. Still, the suggestion of analogy is hopeful, and it is rendered more probable by the discovery of the titanium flutings in Sun spots.

The Sun, it will be remembered, is of Type II, the variables of Type III, but the boundary line is not very sharply defined. According to this theory the spottedness is likely to become more pronounced, though we do not know whether such intense light changes as those of Mira are reached by all stars or only by a few. If they are reached in our case they will probably render the system uninhabitable.

Professor Turner has recently studied the analogy of the Sun and variable stars under another aspect. He recalls the changes of latitude of Sun spots that take place during the cycle, and points out that if we viewed these from a point distant from the Sun's equator, the character of the variation would be modified. He has thus found that he can explain the different curves shown by the stars. These can be arranged so as to form a sequence according to the proportion of the waxing to the waning phase:

"If one of the star's poles were towards the observer, the faculæ in high latitudes would be most obvious, the equatorial faculæ being subject to foreshortening and absorption. The minimum would then follow the maximum early. Conversely, if the star's equator were towards us, it would be late."

He examines whether the hypothesis gives any clue to the general positions of the stars' axes. A tendency to parallelism with the Milky Way is indicated:

"We should then see stars equatorially in all directions, but we should not have a polar view of those lying near the galactic poles".

This is found to agree with the facts, and the theory is full of promise but there is one remarkable difference between the Sun and stars, *i.e.* the period of the Sun is much longer than that of the variables. We do not know the cause of this period; it may be that as the variation becomes more accentuated it will grow shorter. Professor Schuster already suspects shorter waves superposed on the eleven-year one, and it is quite possible that these may in time overpower the former.

CHAPTER VII

THEORIES OF COSMOGONY

LAPLACE'S NEBULAR HYPOTHESIS

HIGHLY SPECULATIVE NATURE OF THEORIES OF COSMOGONY.—We have now finished our survey of the various types of heavenly bodies. We pass on to examine whether we can deduce a probable theory of cosmogony, *i.e.* of the steps through which our system has passed before reaching its present condition. It is necessary to state that nothing is known for certain on the matter; indeed it is hardly likely that such will ever be the case. It is sufficiently surprising that we should be able to form the smallest conception of these mighty processes, whose movement is so majestically slow that it is as nothing during the period over which our observations extend.

THE PRIMEVAL NEBULA.—There are strong reasons for thinking it likely that our system was developed from matter that previously formed a large extended cloud covering all or most of its present area. The fact of the planets all moving round the sun in the same direction and in nearly the same plane is an argument for this, another less powerful one being the number of terrestrial elements found to exist in the Sun. Laplace's famous hypothesis supposed that the solar system once formed a spherical nebula of extreme tenuity, filling the space bounded by the orbit of the outer planet. This nebula contracted under gravitation, the speed of rotation increasing with the contraction till an equatorial ring was thrown off by "centrifugal force". This ring was supposed to have formed the outermost planet, and the others followed in succession.

OBJECTIONS TO LAPLACE'S THEORY.—Laplace's idea seems to have occurred to him independently of Herschel's discovery of a shining fluid in

space, but obviously the discovery helped the hypothesis. The latter has not, however, stood the test of critical examination. So large and tenuous an object would have no rigidity, and would not rotate as a solid sphere. Further, Mr. F. R. Moulton has recently shown that the principle of "conservation of moment of momentum" is fatal to the hypothesis as it stands; for if the nebula when filling Neptune's orbit were rotating in Neptune's period, this moment would have 213 times its present value.

INITIAL DIFFICULTIES.—While mentioning this conservation it is a convenient place to say that the mutual gravitation of the system is powerless to produce any moment of momentum; the fact that such exists shows that it must either have been initially impressed on the nebula, or have been the result of motions in its constituents before they came together, due to the action of external bodies. This clearly only shifts the difficulty back a step, and, indeed, science is powerless to explain the manner in which the moment of momentum of the system took its origin. This is one of the many points where an attempt to give a complete explanation of all the phenomena of nature on a purely rationalistic basis breaks down completely.

MODIFICATIONS OF LAPLACE'S THEORY.—One temporary set-back that the hypothesis received in the last century has now been reversed. It was supposed that Lord Rosse's great reflector had shown all the nebulae to be stellar, and therefore disproved Herschel's shining fluid; but the spectroscope has now confirmed Herschel, and shown that many of them are truly gaseous. Further, the manner of their association with stars in the Pleiades and elsewhere is demonstrative of a close connection; there is a strong case for supposing that some at least of the nebulae are embryo systems. Two principal modifications of Laplace's scheme have been proposed: (1) the substitution of a thin plane spiral for his nebulous sphere; (2) the introduction of tidal action to explain many of the details. The first assumption diminishes the extreme tenuity of the nebula, and we also find such spirals in great numbers in the heavens.

METEORIC THEORIES

SIR N. LOCKYER'S THEORY.—There have been two ideas about the nature of our primeval nebula: (1) that it was meteoric, (2) that it was gaseous. Sir N. Lockyer advocated the former view, basing it on spectroscopic grounds: he thought he had identified the chief nebular lines with those of magnesium, as given off from meteors. The identification, however, has been disproved; moreover, meteors are such complex bodies that

ASTRONOMY

It is difficult to picture them as the primal world-stuff. They are probably rather the debris of worlds, perhaps expelled from suns or planets in mighty eruptions. Sir R. Ball thinks most of them are Earth-born, and this may be true for many.

COMETS AND METEORS.—There is a close connection between comets and meteors, showing that the latter may be associated with gaseous matter; perhaps the gas in this case was previously imprisoned in the meteors, and driven out by the heat or light pressure of the Sun. The gases of comets are not like those of nebulae, being chiefly cyanogen or other carbon compounds. In Lockyer's view the meteors would frequently collide, and the heat generated would gradually reduce the swarm to gas. Sir. G. Darwin suggested as a modification that a dense meteor swarm might itself act as a gas, their impacts replacing those of the gaseous molecules. This theory, however, has not met with much support.

SIR R. BALL'S THEORY.—Sir R. Ball has proposed one form of the spiral hypothesis. He starts by laying down that a sphere of moving particles has a tendency to spread itself out into a disc, and deduces this from the fact that the moment of momentum is constant, but the "energy" of the system continually diminishes with each collision. The particles after collision would drift towards the centre, and the system tends to that form which combines a minimum of energy with the maintenance of its original moment. This can be shown to be an extended plane disc. The drift of particles towards the centre would cause this part to rotate more rapidly than the outer part, which would of itself produce a spiral structure. In some way, of which we cannot trace the details, knots or centres of condensation appeared on the whorls of the spirals, and these formed the embryos of the planets.

PROCTOR'S VIEWS.—Proctor endeavoured to explain the sizes of the different groups by the consideration that near the Sun his influence would be so paramount, and the velocities of the particles so high, that they would prevent any large aggregation of matter; thus the first four planets are small, that nearest the Sun being the least. The giant Jupiter is formed in a region where the Sun's influence has much diminished. Proctor suggested that his disturbing influence might have prevented the minor planets from forming one orb. The reason of the decline in size outside Jupiter he supposed to be due to the growing paucity of material as the outskirts of the system were approached.

Enormous tides were raised on two opposite sides of each sun, sufficiently powerful to tear off great quantities of matter, though in our Sun's case it only amounted to one-seven-hundredth of the total mass. The torn-off matter would have returned to each sun but for the perturbing effect of the other, which gave it a moment of momentum and left it describing ellipses.

STAGES IN EVOLUTION.—They show that the matter would arrange itself in a double spiral exactly like the forms seen in the nebulae. It should be noted that the streams of the spirals are not the directions in which matter is moving, but the regions in which it is most densely collected. Each particle is moving at a large angle athwart the spiral, and in consequence the whorls of the spiral nebulae should in the course of time show a rotation, and also become more and more coiled. The plane of motion of the matter would be nearly the same as the plane of relative motion of the other sun, and it is conjectured that tidal action may have brought the Sun's original plane of rotation near this plane. The larger a planet grew by the collection of particles, the more nearly would its plane coincide with the mean plane of discharge of all the particles.

SOME FACTS EXPLAINED BY THEORY.—The smaller inclination of the planes of the large planets is thus explained. It is even suggested that the more rapid rotation of the Sun's equatorial regions may be explained by more matter having returned to him in this plane, which would transmit the moment of momentum it had acquired during its flight by the action of the other sun. It is also shown that successive collisions of particles to form planets would tend to reduce the eccentricity of the orbits, thus explaining the nearly circular orbits of the large planets. The properties of satellite orbits are reasoned out in a similar manner, and shown to result in nearly circular orbits, not far distant from the plane of their primary.

It should be noticed that on this theory each whorl of the spiral is

not the embryo of a separate world. A whorl may, in fact, contribute matter to several worlds, and a world may draw matter from portions of several different whorls which are at about the same distance from the Sun.

INITIAL ASSUMPTION UNLIKELY.—In fine, if we grant the initial assumption of the very near approach of two suns, the rest of the theory seems to work satisfactorily; but such an approach must be so rare an occurrence that one hesitates to accept it as an integral part of the growth of the system, unless driven to do so. If the two suns were alike in mass and condition, each would suffer the same tidal action, and presumably a similar system for each sun would be the result.

STAGES OF STELLAR AND PLANETARY COOLING

TEMPERATURE OF PLANETS NEVER SO GREAT AS THAT OF SUN.—Whatever theory we adopt for the earlier stages in the evolution of a stellar system, we come to a time when such a system had developed into a number of large orbs, all raised to a high temperature by the coming together of their constituents. This temperature would vary with the size of the bodies. It is not likely that the smaller planets were ever in a sun-like state, and even the giant planets only approximated to it. The small worlds would also cool more rapidly, as is exemplified by the Moon. The Sun may still have been semi-nebulous when the Earth's crust was formed.

PROBABLE LIFE HISTORY OF SUN.—The Sun is presumed to have passed through the stages represented by the spectral types, being first a helium star of great tenuity, perhaps with nebulous appendages. On this would follow the Sirian stage, when the photosphere was intensely luminous, and unveiled as yet by the reversing layer. It is probable that this was a more prolonged stage than the first, for the type is much commoner than the helium one. By slow stages it would pass into the present golden-yellow condition. As more and more of the blue light was cut off, the light would grow redder, and probably the spot variation more pronounced.

At least in Arcturus, which is believed to be in the late solar stage, spot lines are found in the spectrum, which seems to imply that its surface is much more spotted than the Sun's. Looking further ahead, we conjecture that it will pass through the Type III stage, when its colour will be decided red, owing to the strong titanium flutings. Probably its light will then be markedly variable, and there will be a liability

to great outbursts of glowing gas; further than this we need not try to go.

EVOLUTION OF LARGER STARS.—It used to be thought that the larger stars would in all cases take longer for each of their stages. This is undoubtedly true for the total radiation of their heat, but doubts have been raised as to whether it is true of the duration of Types I and II. Thus Mr. Lewis has demonstrated that in the majority of cases tested the fainter star of a pair is the more massive, the presence of a photosphere involving such a delicate balance of conditions that it may well be, as Sir W. and Lady Huggins suggest, that powerful surface gravity hastens the transformation from the Sirian to the solar stage. Capella, for example, which exceeds our Sun greatly in mass, has a spectrum very similar to his, though, from the relation of light to mass, Capella's density is presumably much smaller; in other words, it has passed more rapidly to the solar stage, before the density has increased to a corresponding degree. In the case of the fainter but more massive components of binaries, probably the blueness does not arise from a Sirian condition, but from some later stage of development that is not, as yet, quite understood.

INFLUENCE OF SOLAR TIDES ON PLANETARY ROTATION

DIRECTION OF ROTATION HAS BEEN REVERSED.—We shall now leave the Sun, and pursue in greater detail the probable course of the development of planets. Laplace explained their direct rotation by the supposition that they had previously existed as rigid rings, in which case the outer portion would be moving most rapidly round the Sun. When the ring coalesced into a sphere this would result in a direct rotation. But we now know that such a ring could not move as a rigid body; each portion would have the speed appropriate to its distance, as is now the case in Saturn's ring, and this would lead to a retrograde rotation. Now, evidence has recently been discovered that the primitive rotation of the planets was retrograde, but that solar tides have reversed it.

PICKERING'S RESULTS—PHOEBE.—The most striking evidence for this was the discovery by Professor W. H. Pickering of an outer satellite of Saturn (Phœbe), which proved to be moving round the planet in a retrograde direction in opposition to all the rest. He at once suggested that the satellite was the oldest of Saturn's family, and remained as a witness of the primitive direction of rotation. It then struck him that this would likewise explain the retrograde motion of the Uranian and

Neptunian systems. He was able to base a striking argument on the behaviour of a gyroscope :

"If a gyroscope properly balanced and mounted in gimbals is placed on a table while spinning, and the supporting stand made to rotate about a vertical axis, the wheel will adjust itself so as to rotate in the same direction as the stand and about a parallel axis. If the direction of rotation of the stand is reversed, the wheel will turn over and again rotate in the same direction as the stand. Or if an observer hold a rotating gyroscope at arm's length, and rotate upon his heels, the gyroscope will adjust itself so that its rotation is in the same direction as its orbital revolution, the two axes being parallel. If the observer reverse his direction of rotation the gyroscope again turns over. When the planets were first formed they rotated in directions opposite to the orbital revolutions, as Neptune now does. In former times, when the planets were large, diffuse bodies, the tides raised by the Sun would act in the same way as the rotation of the gyroscope stand. Neptune is so remote that his plane of rotation has been shifted only about 35 degrees; Uranus, 82 degrees; Saturn, 153 degrees; Jupiter, 177 degrees. Phœbe was born whilst Saturn still retained its original plane of rotation, hence its retrograde revolution. The other satellites have been subject to the tidal action of the Sun, tending to bring the orbit into the plane of Saturn's orbit, and to that of Saturn, tending to bring it into the plane of Saturn's equator. The latter has predominated in the case of the inner satellites."

STRATTON'S RESULTS.—Mr. F. J. M. Stratton investigated this bold hypothesis mathematically, making the investigation as rigorous as possible, though it necessarily included some assumptions on the early condition of the planets that cannot be regarded as quite certain. His results are favourable to the hypothesis, as the following quotation shows :

"Saturn shed Phœbe, and possibly also Jâpetus and Hyperion, while its obliquity was greater than 90 degrees; as under solar tidal influence it passed through the critical position, where its obliquity was 90 degrees, Phœbe sank down into the ecliptic in a retrograde orbit, while Japetus and Hyperion moved over with the planet's equator. Afterwards the inner satellites were evolved, and under their influence and the influence of the rings Saturn's obliquity has steadily diminished and is still diminishing towards a small stable value. As seems highly probable for a planet farther removed from the Sun, and therefore less likely to have its increasing rotation checked by solar tidal friction, the satellites of Uranus were evolved in an earlier stage of its evolution, before its obliquity had decreased to 90 degrees; they have stopped the decrease in obliquity which would arise from the solar action, and they are now driving Uranus back to a stable position with an obliquity of 180 degrees. Neptune, with its one satellite of extremely large tidal influence, is being driven towards an equilibrium position with an obliquity of 180 degrees."

The two planets nearest to the Sun have no satellites. Yet here, too,

the solar tides have left their mark, if we accept as true what is still somewhat doubtful, the fact of their always turning the same face to the Sun. We must, indeed, suppose that tidal action was so potent that it prevented their rotation speed ever rising to a value that would lead to disruption; tidal action, it may be pointed out, varies as the inverse cube of the distance, which explains its great importance for the two nearest planets.

BIRTH OF THE MOON

UNIQUE HISTORY OF EARTH AND MOON—THEORY OF SIR GEORGE DARWIN.—We come now to our Earth, whose history, there is reason to think, has been unique in the system. There is no other planet which has a satellite with a relative mass anything like so high as that of our Moon. Miss A. Clerke has pictured the circumstances of the Moon's birth in a passage so graphic that it deserves reprinting:

"How the Earth was to fare . . . long hung in the balance. Rightly to forecast its destiny would indeed have demanded no common perspicuity in an intelligent onlooker. Although the solar drag upon its rotation had no more than one-eleventh of its power over Venus, it sufficed during uncounted ages to hinder acceleration from reaching the pitch involving instability. Our embryonic planet had long ceased to be nebulous, and had, in fact, shrunk by cooling nearly to its present dimensions before the die was cast. Then at last the hurrying effects of contraction prevailed over slowing down by tidal friction, axial speed overbore equilibrium, and the spheroid divided. Now globes thus far advanced in condensation are apt to split less unequally than globes in a more primitive stage; and the Moon, because late born, was of large size. Its mass is the one-eighty-first of the Earth's; the masses of Titan and Saturn are as 1 to 4600; while Jupiter's third and greatest satellite contains only the one-eleven-thousand-three-hundredth part of the matter englobed in the parent body. Moreover, Professor Darwin has made it clear that the satellites of Jupiter and Saturn revolve now in orbits not widely remote from those at first pursued by them; the Moon, on the contrary, having started on its career almost, if not quite, from grazing contact with its primary. . . . It was revolving, when our theoretical acquaintance with it begins, in a period of not less than two and not more than four hours, quite close to the Earth's surface, while the nearly isochronous rotation of the Earth was conducted with all but disruptive rapidity. The situation is so suggestive that it needs only a short and tolerably safe leap in the dark to the conclusion that the two globes had very recently been one. With their division, at an epoch estimated to have been at least 54,000,000 years ago, the process began by which the Moon was pushed back along a widening spiral course to its present position."

DARWIN'S RESEARCHES.—This theory of the Moon's birth was put

forward by Sir G. Darwin in 1881, and is now generally accepted. The moment of momentum of the Earth-Moon system is constant, except for the slight effect of solar tides. Hence, as the Earth's rotation grows slower under the brake of the tidal wave, the Moon must recede in order to conserve it. The tides on the Moon have already made her periods of rotation and revolution identical. She is endeavouring to do the same for the Earth, but it is doubtful whether she will ever completely succeed. Initially each turned the same face constantly to the other; then, as the Moon receded, the number of Earth rotations to one lunar revolution increased, very rapidly at first, so that Sir G. Darwin calculates it had a maximum of 29 about 46,000,000 years ago. Since then it has declined to its present value of $27\frac{1}{3}$, the retardation growing slower and slower, so that it will probably never get back to 1.

COWELL'S WORK ON ECLIPSES.—We can, perhaps, trace some effect of the lengthening of the day, and the accompanying recession of the Moon, by studying ancient eclipses. Mr. P. H. Cowell has recently done this for all the old eclipses of which the records are sufficiently precise, starting with one observed in Babylon in B.C. 1063. He finds that these early eclipses show an apparent acceleration of the Sun, which probably really arises from a lengthening of the day. The effect on the Moon is made up of two parts; the day being longer the Moon will seem to move farther in a day, but her increasing distance will have the opposite effect. This explains why the effect on the Sun is such a large fraction of that on the Moon. The result indicated is that the day is lengthening by one-two-hundredth of a second per century.

AGE OF MOON—PICKERING'S THEORY.—Professor Darwin puts the date of the Moon's birth as about 57,000,000 years ago, but he does not claim that the date can be fixed with any precision. At that time the Earth was but slightly larger than now, and rotated in between three and five hours. Professor W. H. Pickering has recently examined whether we can now trace on her surface any evidence of the disruptive catastrophe. He has put forward the following bold theory, which is hardly likely to gain general acceptance, but which is so interesting that it is worth giving. He postulates that, prior to the disruption, the Earth was already covered with a crust 36 miles thick, of density 3.2, slightly less than the Moon's present density (3.4). As it cooled it contracted, till, under the combined influence of centrifugal force and solar tides, the breaking-point was reached, and three-fourths of the crust was torn away, forming a swarm of small fragments, later to be concentrated into the Moon. The heat resulting from their collisions would suffice

to reliquify portions of the Moon, thus accounting for the obvious signs of volcanic action on her surface. The region thus torn away is supposed to have been the Pacific basin, while the remaining one-fourth is supposed to have been torn in two by the shock, and formed the two great continental masses. In this way Pickering explains the remarkable parallelism of the two sides of the Atlantic, which had already been noticed by others.

If the specific gravity of the land masses was 3.4, and that of the liquid in which they floated 3.7, the average height of the continents above the ocean beds (3 miles) would be accounted for. The volcanic islands would have been formed later; the great density 3.7 found for the lower portion of Mauna Kea, Hawaii, is in favour of its having been formed from the consolidation of the dense liquid. Pickering suggests that borings undertaken there for a few hundred feet would bring to light materials existing elsewhere at a depth of many miles. He considers that the ring of volcanoes encircling the Pacific also favours his view. He has not forgotten the great changes of coast line that are continually taking place, but he holds, with many geologists, that the main forms of the continental masses have been permanent, and that the submergence of portions of them has been only temporary, and the covering water only a shallow sea, not a deep ocean.

The fact that this view implies that the Moon left the Earth as a swarm of fragments is in full accord with Sir G. H. Darwin's conclusions, for he points out that there is a certain distance (known from its discoverer as Roche's limit) within which a satellite could only exist in a fragmental form, and this distance in our case is 11,000 miles, so that the Moon could not have coalesced into a sphere till it reached this distance from the Earth. Pickering notes as an interesting point that Phobos, Mars' inner moon, is very near the limit, and that we have reason to think solar tides are making it approach the planet; since its period is much less than the rotation of the latter. Hence, if it approaches nearer, it will be torn to fragments and lost to the view of astronomers. We have an example of such a swarm of fragments in Saturn's ring, which lies within Roche's limit.

THE EARTH'S INTERIOR

MEAN DENSITY OF EARTH.—The interior of the Earth was formerly *terra incognita*, and our knowledge of it is still scanty, but a few important facts have been learnt. The first of these is the mean density,

which is found by comparing the Earth's gravitational pull with that of a sphere of metal. Very delicate measures by Boys and Braun agree in giving the mean density 5.527 times that of water, about double that of the materials at the surface. Professor Wiechert suggested that the Earth's interior might be iron, basing this on the agreement in density (that of iron being 7.8) and the large amount of iron found in meteors. This view is not impossible, but it involves a discontinuity between the constitution of the surface and interior for which there are no strong reasons. Professor See suggests, with more probability, that—

“the matter in the interior of our globe is of the same general character as the lava which flows from our volcanoes, simply compressed by the enormous weight of the superincumbent matter surrounding it on all sides”.

INTERIOR MORE RIGID THAN STEEL.—Several lines of proof converge to show that, whatever the chemical composition of the interior, it is solid throughout, and more rigid than steel. This is proved, (1) by the period of the small oscillation of the pole known as “The variation of Latitude”. Professor Chandler discovered this in 1893, and found the period to be 427 days, while it had been previously supposed that it must be 305 days. Professor Newcomb found the flaw in the latter result, which made no allowance for the elasticity of the Earth. He showed that the period 427 days indicated a rigidity rather greater than that of steel. (2) Lord Kelvin, continuing Hopkins's work on the subject, showed that either the Earth's interior is solid or that the outer crust behaves with regard to external strains as though it (the crust) were liquid. The phenomena of ocean tides negative the latter, and therefore prove the former. (3) Another proof is afforded by the seismograph records of distant earthquakes. There are generally at least two distinct records of a disturbance, the first of which is the feebler, and which is concluded to be due to a wave of compression passing in a straight line through the body of the Earth. The velocity of this wave has been taken to show a rigidity greater than steel, though, as we do not know the exact path of the wave, this is open to some doubt.

ESTIMATES OF CENTRAL DENSITY.—The rate of increase of density is uncertain. Professor See, on the assumption that all matter under such enormous pressures would behave like a monatomic gas, deduces a rapid rise, so that at a depth of half a radius the density would be 9, and would then increase more slowly to 11 at the centre. Others, however, think that there is a definite limit to the compressibility of solid substances, even under infinite pressure, and would put the central density not much

above 7. Whether Dr. See's figures are strictly accurate or not, the following quotation from him probably gives a good general idea of the condition of the Earth's interior:

"If, in addition to perfect interpenetrability of matter under planetary pressure, we imagine an enormously high temperature which would instantly vaporize the most refractory elements, we may conceive most of the matter in the interior of the Earth and similar planets has the property of a rigid fluid, a gas rendered more rigid than steel by its confinement, but capable of expansion with a violence surpassing the eruption of Krakatoa if the pressure could only be removed".

THE AGE OF THE EARTH AND SUN

ESTIMATES OF SIR GEORGE DARWIN AND LORD KELVIN.—Astronomy is unable to give a precise answer to this question, not having sufficiently accurate data available. Sir G. Darwin's estimate of 57,000,000 years for the Moon's age is confessedly rough, though it is not a mere guess, and has been made with great care, but we are unable to determine accurately all the constants required. He considers it unlikely that the time exceeds 100,000,000 years. Lord Kelvin estimated the Sun's age as 20,000,000 years, from the amount of energy produced by the coming together of its constituents from a great distance, and the amount now being radiated in the form of light and heat. But the radio-active elements have since then been discovered, and it is now known that in these at least, and by presumption in other matter as well, the energy imprisoned within the atom so enormously transcends all external sources of energy that these by comparison sink into absolute insignificance.

Hence it is recognized that Lord Kelvin's estimate has broken down, though it is not yet possible to replace it by a revised one. We do not know the amount of the radio-active matter in the Sun, nor whether other elements may not become radio-active under the conditions that prevail there. The fact that helium seems to play such an important part in the early history of suns—helium being one of the radium emanations—certainly warrants us in concluding that these radio-active processes may indefinitely extend Lord Kelvin's estimate of the Sun's age, and bring it more into accord with geological ones. These have perhaps erred by excess, in not making sufficient allowance for the more energetic meteorological and tidal processes that doubtless prevailed in distant ages, owing to the shorter day and the greater proximity of the Moon, so that there does not seem to be an irreconcilable discordance between the two.

CHAPTER VIII

ASTRONOMICAL RELATIONS THAT AFFECT
THE EARTH'S PHYSICAL CONDITION

THE OBLIQUITY

As was stated at the beginning, every physical process on the Earth's surface, with the possible exception of those due to volcanic activity, can be traced directly or indirectly to the Sun; were his light and heat withdrawn, universal frost and stagnation would prevail. The trade winds and aerial and oceanic circulation generally depend on the Sun's heat conjoined with the Earth's rotation. These, however, are usually treated under the heading *Physical Geography*. One relation of great importance to our wellbeing is the amount of slope of our equator to the ecliptic or plane in which we travel round the Sun.

EFFECT OF LARGE CHANGES.—This is directly concerned with the seasonal change, for were the two planes coincident there would be only the very slight temperature changes due to the Sun not being exactly in the centre of our orbit. Were the angle, on the other hand, to be considerably increased, we should have seasons of much greater rigour, which would render large tracts uninhabitable. The present value of the angle is $23^{\circ} 27'$, and it only changes between narrow limits. Professor Newcomb calculates that it was at a maximum ($24^{\circ} 13'$) about 9100 years ago, and will reach a minimum ($22^{\circ} 35'$) about 9600 years hence.

OBLIQUITY NEVER EXCESSIVE DURING GEOLOGICAL TIME.—Mr. Stratton's work on the action of solar tides has been already described. Assuming an initial retrograde rotation for the Earth, these would tend to produce a direct one in the plane of the orbit. Since the Moon's motion is direct, it follows that this action must, if it took place at all, have made the rotation direct before the Moon's birth. Since this birth the Moon's action has been more potent than the Sun's, and Sir G. Darwin concludes that at an early stage in the Moon's history, when she went round the Earth in twice the time that the latter rotated, the obliquity was about 11 degrees. The fact thus remains that during the geological ages the obliquity has never been excessive, and the tendency of the Moon to increase it is now less owing to her greater distance, and is controlled by the opposite action of the Sun. It will probably never much exceed its present value.

CHANGING ECCENTRICITY OF THE EARTH'S
ORBIT—ICE AGES

VARYING DISTANCE OF EARTH FROM SUN.—We may then take the obliquity as sensibly constant for the greater part of the geological period, but there is another astronomical relation which there is reason to think has produced most startling changes in the habitability of large regions of the Earth's surface. This is the change in the eccentricity of her orbit round the Sun. We may express this in simpler language by saying that the orbit is always sensibly circular, and always of the same size, but that the position with regard to the Sun varies; sometimes he is exactly in the centre, at others he may recede from this point as much as 7,000,000 miles, or one-fourteenth of his distance. If at such a time, we suppose midsummer to coincide with the Sun's nearest approach, he would be south of the Equator five weeks longer than north of it. If midwinter occurred at nearest approach the relation would be reversed.

RESULTS OF SIR ROBERT BALL.—Such changes are actually taking place, under the influence of the planets, more especially Venus and Jupiter, on the Earth's orbit, and their effect has been very clearly traced by Sir R. Ball in *The Cause of an Ice Age*. Geology shows that large regions in Europe and elsewhere have been in the past covered by glaciers in the manner that Greenland is now, which Sir R. Ball accounts for by proving that each hemisphere receives 63 per cent of its annual supply of heat during its summer half-year, and 37 per cent during the winter half. Now if midsummer was the Sun's nearest approach at a time when the eccentricity was very great, the 63 per cent would be poured in during 166 days, while the 37 per cent would be spread over the remaining 199. There would consequently be a long, severe winter and a short, hot summer, which would not be able to melt all the snow of the winter, especially as much heat would be reflected away by the white surface without being absorbed. Hence the snow would grow thicker year by year till it formed a mighty sheet. The opposite hemisphere would enjoy a genial climate with a long, moderate summer, and a short, mild winter. This would clear away the ice cap almost, if not quite, up to the pole, and Sir R. Ball thus accounts for the fossils of temperate plants found in high latitudes.

The axis of the Earth's orbit is moving in such a way that the conditions are changed in either hemisphere from glacial to genial, and vice versa, in a period of about 10,000 years; and at a time of high eccentricity there will be a succession of glacial and genial periods alternating in the two hemispheres. Sir R. Ball suggests that the animals and plants driven

from one hemisphere may have taken refuge in the other, but this, however, does not seem necessary, for a migration to the region just free from the ice sheet would probably suffice.

He gives the following table, showing the average daily receipt of sun heat by each hemisphere under the several conditions:—

PRESENT TIME (NORTH HEMISPHERE)

Mean daily sun heat in summer (186 days) 1.24.

Mean daily sun heat in winter (179 days) .75.

GENIAL CONDITIONS

Mean daily sun heat in summer (199 days) 1.16.

Mean daily sun heat in winter (166 days) .81.

GLACIAL CONDITIONS

Mean daily sun heat in summer (166 days) 1.38.

Mean daily sun heat in winter (199 days) .68.

This table seems to prove that the theory affords amply sufficient machinery for the production of an ice sheet, though it is right to say that some have contested this point. Of course the climate of a country is the product of complex conditions, which might largely influence the figures given above. For example, any change in the direction of the Gulf Stream would profoundly influence the climate of western Europe, as we see by comparing Greenland and Norway, which do not differ greatly in latitude, but which have cold and warm currents flowing along their shores.

We now enjoy a faint approach to a genial climate in our hemisphere, since our winter is eight days shorter than our summer. The present eccentricity—one-sixtieth—is, however, too small to have very much effect, though it is doubtless responsible for the greater degree of cold that appears to prevail in the Antarctic regions as compared with the Arctic, in spite of the moderating influence of the oceans that surround the former.

ALTERNATION OF GLACIAL AND GENIAL EPOCHS.—Sir R. Ball points out so graphically the potent influence of the planets on our earth, far exceeding anything imagined by astrologers, that I give some quotations from his book:

“The influence of the planets has occasionally visited some of the fairest regions of our globe with a scourge more deadly than the most malignant pestilence, more destructive than the most protracted of wars, and more desolating than the mightiest of floods. Slumbering in the Arctic regions lies at this moment the agent of the most dire of calamities. . . . Time after time it has happened that the planets by their influence on the Earth's orbit have brought down on our temperate

regions the devastations of the great ice sheet. . . . It was the planets that drew down this icy invasion, and it was the planets which bade the ice to withdraw, . . . chased it entirely from the hemisphere, and permitted the horrors of the ice age to be forgotten in the joys of the summer by which it was succeeded. . . . When we gaze on the Cloghvorna stone a fanciful person might almost think that it saw the thews of mighty Jupiter himself that tipped that stone from its perch some miles away, and sportively cast it down on the mountain side. . . . How do we imagine the characters on the stone as having been placed by the old hand of Venus herself."

EPOCHS OF MAXIMUM ECCENTRICITY.—Attempts have made to fix astronomically the periods of different ice ages, but it is doubtful whether the formulæ used can be trusted as sufficiently accurate for such immense time intervals; it is, however, of interest to give, with this caution, a few of the results that have been arrived at by Croll, Stockwell, Charlier, and Macfarlane.

The eccentricity reached its greatest possible value of one-fourteenth 850,000 years ago, and remained near this for about 60,000 years. The greatest glacial periods must have taken place at this time. There have been other less strongly marked maxima of eccentricity since then intervals of about 100,000 years. The last was 100,000 years ago, its value being one-twenty-first, or three times the present value. This may have been sufficient to cover our islands with an ice sheet, but it is impossible to fix the value that would suffice for this purpose. For the next 100,000 years the orbit will be less eccentric than at present, so obviously no return of the ice is to be apprehended in the immediate future.

PRESENT ECCENTRICITY.—In fact, the earth is passing through a quite unusually prolonged period of small eccentricity, which is obviously favourable for the habitability of the temperate zones. The present diminution of eccentricity is responsible for an acceleration of the Moon's motion of 6 seconds per century. This, however, is of an oscillatory character, and will be reversed in 24,000 years, when the eccentricity will again begin to increase. The acceleration due to tidal retardation will always be in the same direction. Many books do not distinguish between these two different accelerations.

WATER VAPOUR NECESSARY FOR AN ICE AGE.—It should be noted that for an ice sheet to form we need not only long, cold winters, but also an abundance of water vapour in the air to be deposited as snow. This water vapour would be raised from the oceans in the warmer regions, so that even a great ice sheet bears witness to the Sun's heating power. We may emphasize this by pointing out that the southern hemisphere of Mars

at present suffers from much more glacial conditions than ever prevail on Earth, the winter being seventy-five days longer than the summer; but the unmeltable ice sheet does not form, since there is not enough vapour to produce such a thick deposit. Hence the summer sun sometimes melts the cap right up to the pole, and always nearly to this point.

IS THERE AN ELEVEN-YEAR WEATHER CYCLE?

We now pass on to consider the effect of the Sun-spot cycle upon the Earth. In view of the conspicuous changes that are exhibited in all solar phenomena there would be nothing surprising in a striking effect on the Earth's meteorology. It is difficult to understand the following passage in Proctor's *Old and New Astronomy*, p. 350:

"As for the idea that Sun spots may exert specific influence on the weather of different parts of the Earth, it is, beneath the dignity of science to discuss a notion worthy only of the first beginnings of astrology".

NO DEFINITE LAW DETERMINED.—Considering the delicate balance that exists between the contending elements determining our weather, it seems to me that the a priori probability would be rather in favour of a Sun-spot effect being traceable. It must, however, be admitted that, in spite of many attempts, no definite law has yet been detected. Sometimes there is the appearance of such a connection for one or two solar cycles, but afterwards it vanishes. Many secondary weather effects, such as the price of corn, famines, &c., have been examined. In regard to the last, Dr. Lockyer has found an apparent connection between the spot curve and Indian famines, which may prove to be genuine. Some take the line, which seems to me a mistaken one, that an effect on the weather, if really connected with the Sun-spot curve, must be the same all over the Earth, or at least over a hemisphere.

VERDICT "NOT PROVEN".—The effect might be to modify the direction or the strength of the atmospheric and oceanic circulations, and so appear to have opposite effects on two places not very far apart, by diverting some warm or cold current to reach one instead of the other. So if any one station should show an effect in any of its weather phenomena closely following the Sun-spot curve, we need not be deterred from accepting it by the fact that some other station fails to show it, or perhaps even shows an opposite one. This would only show that a negative correlation existed between the two stations, and weather statistics give examples of such a relation. In short, the verdict on the question whether

Sun-spots influence the weather must be at present "not proven", but we are not authorized in asserting that no such connection exists.

ELEVEN-YEAR CYCLE IN TERRESTRIAL MAGNETISM AND AURORÆ

VARIATIONS IN TERRESTRIAL MAGNETISM—MAGNETIC STORMS.—There is, however, a direction in which the Sun-spot effect is palpably evident; that is the Earth's magnetism. At magnetic observatories photographic traces are taken of the direction and dip of the magnetic needle and of the intensity of the force. All these elements show a daily fluctuation indicating the action of the Sun. The amount of this fluctuation waxes and wanes in an unmistakable manner in accordance with the cycle, being greatest at spot maximum. Moreover, there are occasional "magnetic storms", when all the elements are violently perturbed, and such storms generally coincide with some notable spot on the Sun.

MAUNDER'S RESULTS.—We have already alluded to the result found by Mr. Maunder, that magnetic disturbances are apt to recur at intervals separated by about twenty-seven days, the period for a given meridian of the Sun to return to the centre. This proves that the exciting cause resides in some special regions of the Sun, from which it is radiated, not in all directions, but along definite stream lines, which he compares to the long narrow rays in the corona. There is frequently some conspicuous spot near the centre of the disc at the time of the magnetic storm, in which case we can with great probability connect the two. A tendency has been noticed for the storms to follow the central passage of the spot by about one and a half day, so that this would be the time for the stream to travel to the Earth. This, however, is speculative, for we do not know that the discharge was along a radius of the Sun. We naturally associate these supposed streams with the tails of comets, which are supposed to be repelled from the Sun by light pressure.

AURORÆ.—Some years before Mr. Maunder's result, the Swedish physicist Arrhenius concluded that the Sun was continually expelling tiny, electrified corpuscles, which were the exciting cause of the *aurora*, a phenomenon in our upper air which shows a most obvious sympathy with magnetic disturbances. Sir W. Ramsay continued this research, and was able to produce an artificial aurora in a flask, round which a discontinuous electric current flowed. The spectrum of the aurora is found to indicate the presence of the rare gas *krypton*, lately discovered, which has remarkable properties of luminosity. The fact that the aurora is far

commoner in our polar regions shows that the Earth's magnetism also plays an important part in its production. In great magnetic storms, however, it invades much lower latitudes. A remarkable solar outburst seen by Carrington and Hodgson in 1859 was accompanied by an intense disturbance, auroræ extending as far south as Cuba.

CONCLUSION

We shall now briefly sum up the conclusions to which our study of the universe has led us. We conjecture that the "Green Nebulæ", giving a gaseous spectrum, are the embryos of future systems. The gas is probably intensely cold, and shines by electrical excitement. Much solid matter may be scattered through these nebulæ; the spectroscope will only reveal its presence when it has become heated through concentration and collisions. When this stage is reached we call the nebula a "white" one. In some cases the nebula is the parent of a single star, in others of a pair, or even a cluster. When sufficiently condensed it becomes a helium star, after which we suppose that it passes in succession through the Sirian, solar, Antarian, and carbon stages, till finally its life as a sun is over, and it becomes a dark star, of which presumably multitudes exist in space. We cannot tell whether they are destined to play any further part in the scheme of creation.

We described various theories of the manner of development of the planets from the solar nebula, conjecturing that the spiral nebulæ gave the most probable method by which the distribution of matter was effected. We then saw that tidal friction played a most important part in the subsequent development of the subordinate systems, and that it had probably left its traces, though in different ways, on every orb in the system.

We saw the fiery youth of planets exemplified by Jupiter and Saturn, their middle age by the Earth, their decrepitude by Mars, and their death by the Moon; not that all follow identically the same history, but there is a resemblance of type. It may well be that worlds, and even systems, fitted to be the abode of rational beings, are the exception rather than the rule; yet certainly the facts that we have learnt about the universe do not justify us in asserting that our Earth is absolutely unique in this respect.

At this point we break off our study of our world viewed from without as a member of the heavenly host, and leave it in the hands of those who will study it from within, in the light of those records of its past that are stamped upon its surface and embodied in its crust.

LIST OF ASTRONOMICAL WORKS RECOMMENDED FOR FURTHER STUDY

| Name. | Author. | Publishers. |
|--|---------------------------|--|
| THE SUN | Professor C. A. Young | K. Paul, Trench, Trübner. |
| THE SUN | R. A. Proctor | Longmans, Green, & Co. |
| THE MOON... .. | " | A. Brothers, Manchester. |
| THE MOON... .. | T. G. Elger | Geo. Philip & Son. |
| THE MOON... .. | Nasmyth and Carpenter | John Murray. |
| THE MOON... .. | Edmund Neison | Longmans, Green, & Co. |
| A COMPARISON OF FEAT- TURES OF EARTH AND MOON | Professor N. S. Shaler | { Smithsonian Contribu- tions to Knowledge (part of vol. xxxiv). |
| HISTORY OF ASTRONOMY DURING 19TH CENTURY } | Miss A. C. Clerke | A. & C. Black. |
| THE SYSTEM OF THE STARS | " | " |
| PROBLEMS IN ASTROPHYSICS | " | " |
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GEOLOGY

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GEOLGY

CHAPTER I

INTRODUCTORY—DENUDATION IN EXTREME CLIMATES

INTRODUCTORY

EVOLUTION OF SURFACE FEATURES OF EARTH.—Within recent years the methods and results of Geological Science have been applied with marked success to the study of the mode of origin and history of the diverse features of the earth's surface. The majority of these, so far as they are accessible, have been explored, described, and represented on maps or charts by generations of geographers. It is, however, not sufficient merely to describe the globe as it appears at present; it is recognized that owing to various causes its aspect is constantly changing, and that it must have undergone similar change in the past. Old maps and charts record the form and extent in their day of certain coast-lines, islands, and rivers which, on comparison with modern maps and charts of those regions, show evidence of much modification. Similar changes must, of course, have taken place in other regions of which no written record has been preserved. As a rule, the difficulty in obtaining definite historical information concerning geographical modifications increases as the enquiry is pushed back in time, until finally all historical records cease and the geographer is forced to turn to other sources for aid in his enquiry.

It is the aim of the present sketch to indicate how geologists, by studying step by step the complex series of events in the past history of the earth, have been enabled in some degree to supplement the written records, and thus to render a signal service to Geographical Science.

The service thus rendered is not, however, one-sided, for it is within the province of the latter science to study carefully the various agents

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which are causing modifications in the surface of the earth at the present day; without a knowledge of which and their mode of operation the geologist would be powerless to solve the riddle of the past. The two sister sciences cannot, therefore, be separated without seriously crippling both.

DESTRUCTION OF THE LAND.—All land areas are gradually undergoing destruction in a manner and to a degree which varies in different parts of the globe. The material derived by wearing down the land is deposited mainly on the ocean floor, but a smaller part may settle in inland seas or lakes; some, again, may find a temporary resting place on the bottom of valleys or hollows on the land surface, but it generally finds its way in the end to the bottom of the sea. It is now known that this destruction has been going on steadily for a very long period of time, and it has been calculated that in temperate regions the average level of the surface is reduced 1 ft. in 4000 years. At this rate the whole of the present dry land would be reduced to sea level in about 9,500,000 years. As this period of time is but a minute portion of the most modest estimate of the age of the earth, it may be asked how it is that any land remains above the level of the sea?

EARTH MOVEMENTS.—On the other hand, the surface of the earth is subject to slow changes of shape by buckling and warping, which elevate parts of the sea floor and convert them into dry land, to be attacked in turn as soon as it emerges. There are, therefore, forces of repair in constant operation as well as forces of destruction, and according to the relative amounts of these opposing forces the distribution of land and sea in the past has varied greatly at different periods. Each period has had its geography peculiar to itself, and differing from that of every other period. If we could reconstruct these geographies for all past periods we should have the material for a fairly complete history of the earth. With our present knowledge it is only possible to do this in a limited degree at a few critical stages.

It is proposed in what follows to deal in succession with (i) *Denudation* or waste of the land areas, and (ii) *Earth movement* or the production of new land areas; then to indicate how the geographies of past periods can be reconstructed, and finally to trace the various modifications which they passed through before they gave way to the present condition of things.

DENUDATION

OF THE AGENTS OF DENUDATION it is important to distinguish, where possible, between those which break up and reduce the solid rocks forming the land surface (*Weathering*), and those which carry away the broken-up material (*Transportation*). Again, in the process of transportation the fine material wears away by friction the rocks over which it is carried. To this operation the term *Corrasion* has been given by American geographers, and as no English word exactly supplying the need has yet been coined, the American term will be adopted in the following pages. The most rapid waste of land takes place when these various operations are working together. If at any spot weathering is active, but the material is not removed, the cover of destroyed rock becomes so great as to protect the surface underneath from further weathering. On the other hand, if the supply of material is not sufficient for the demand or capacity of the agents of transportation, that process stops for want of material to remove.

ACTION ALONG A SEA-CLIFF.—To make the dependence of these agents on one another a little clearer, let us consider what happens along a sea-cliff. The rocks in the upper part of the cliff are broken up into small fragments by the various agents of weathering which will be considered below, and the fragments fall to the bottom. Here they are battered by the waves against one another and against the solid rocks at the base of the cliff, and still further reduced in size until they can be carried away. During this process the base of the cliff is also being gradually worn away and undermined, thus favouring the slipping of material from above. If, now, the fragments fall faster than the sea is able to remove them, they accumulate at the bottom and prevent the waves from reaching the base of the cliff and undermining it. On account of both these causes the slope along which the material is slipping becomes less and less, until finally the slipping stops and the weathered material remains where it is produced, forming a cover which serves to protect the rock underneath from the weather. The process of destruction or denudation then ceases. On the other hand, suppose the cliff to be so low that at high-water the sea reaches to the top. The action of weathering is therefore very small, and, for the purpose of the illustration, may be supposed to be absent. Water which carries no solid material in suspension has little power, if any, of wearing away solid rock though dashed against it ever so furiously. The waves at the base of our cliff, therefore, not being provided with material to hurl at the solid rock,

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produce scarcely any effect upon it, and the process of destruction again ceases. The case is quite otherwise when the sea is furnished by the agents of weathering with just as much material as it can remove, as frequently happens in the south and east of England, where the coast is made of incoherent sand, soft clay, or chalk. The rate of destruction is then extremely rapid.

The most important AGENTS OF WEATHERING or disintegration are *frost, heat, and vegetation*; while the chief AGENTS OF TRANSPORTATION are *running water, wind, ice, and landslips*. The mode of action and relative intensity of all of these vary greatly with climatic and other conditions; thus in the arid regions near the tropics, where frost is absent, the rocks are broken up by the rapid expansion during the day and contraction during the night; rains are infrequent, but are very violent while they last, and wind becomes an important agent of transportation. In the Arctic regions and on high mountain ranges, where the cold is intense, frost takes a primary part in shattering the solid rocks; there rains are unknown, and the greater part of the material is transported by ice and by the wind. It is important, therefore, in order to obtain a clear idea of the mode in which the surface of the earth is reduced and sculptured by the agents of denudation, to consider separately the action of these agents in—

1. Regions near the Tropics.
2. Regions of great cold.
3. Temperate regions.

DENUDATION IN REGIONS NEAR THE TROPICS

In the sub-tropical regions on each side of the Equator there are enormous tracts where the rainfall during the whole year does not exceed 25 in. and frequently falls below 10 in. As most of the rain falls during a few days, great drought prevails for the remainder of the year, resulting in the formation of deserts. The most important of these rainless tracts extends between 15 and 45 degrees of latitude north of the Equator across North Africa, Arabia, and Persia, into the interior of Asia, and on it occur the principal desert areas of the world. The Sahara, the Arabian Desert, and the Desert of Gobi will serve as examples. In the western hemisphere the arid tracts of Mexico and Colorado lie on the same belt. A corresponding tract extends within the same limits of latitude south of the Equator; on it lie the Peruvian Desert in Western South America, the Kalahari in South Africa, and the great interior desert of Australia.

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An immediate consequence of the absence of rain is the failure of vegetation of the normal type. Most plants are dependent on a fairly regular supply of water; therefore they cannot thrive in desert areas where the supply, though abundant at certain periods, is cut off almost completely for long intervals. In the absence of vegetation the rocks are unprotected from the fierce heat of the sun which pours down on them day after day for months at a time. Deserts are therefore due to a combination of climatic conditions resulting in a small annual rainfall distributed over a few days of the year only, in consequence of which vegetation of normal type is unable to flourish.

INSOLATION.—Under these conditions the processes of weathering are peculiar and interesting. The heat of the sun during the day falls on the rocks unprotected by any vegetation; a part is absorbed and raises the temperature of the rocks, while a part is reflected and heats the air in the neighbourhood. The external layer of rock facing the sun is heated rapidly, while the interior receives heat from the outside by conduction, which in rocks is a slow process. The rise of temperature causes expansion or stretching, and as the outer layer is at first much hotter than the interior, its expansion is correspondingly greater, so that the rock mass is, at it were, encased in a skin which is too large, and therefore, tends to buckle or warp. On account of the extreme dryness of the atmosphere clouds are absent in these regions for long intervals; under these conditions the surface of the earth at night gives off or radiates heat with great rapidity, and the air near the ground is extremely cold. The rock masses then lose the heat which they received during the day, and the process is reversed; the outside layer cools quickly, while the interior is still hot. The skin then contracts and becomes too small; it tends, therefore, to burst or fly apart. By a repetition of these processes day after day and night after night, the surfaces of rocks exposed to the sun peel off in thin plates, and in so doing expose fresh surfaces, which behave in a similar manner. This mode of weathering has been termed **INSOLATION** (exposure to the sun's rays); it depends essentially on great temperature-differences between day and night, which is the most striking characteristic of desert regions. The Desert of Gobi at night has been compared with Siberia, but during the day to the hottest part of India; in half a day the temperature changes 40° C. or 72° F. In the Sahara the difference is still greater, for the thermometer during the day often registers 140° to 160° F., but falls at night to 4 or 5 degrees below the freezing-point of water. It is small wonder, therefore, that the rocks often burst with great violence and with a succession of reports

which has been compared to small artillery fire. The effect is most marked in rocks which are made up of small grains of minerals of different colours (the so-called crystalline rocks); the rate at which heat is absorbed varies greatly with the colour, so that different parts of the rock surface expand and contract unequally. In the Sinai peninsula the granitic rocks have so suffered by this action that a blow from a hammer causes an apparently massive rock to fly into a multitude of small fragments.

TRANSPORTATION.—Having now seen how the solid rocks are broken up, let us consider how the resulting materials are moved from place to place. As the rainfall is extremely small, except at certain periods, running water can play but a small part in this operation, and the work of transportation is carried on almost entirely by wind, which is frequently powerful, and in most desert regions blows from nearly the same quarter for a great part of the year. Wind having a velocity of 16 to 17 miles per hour is capable of driving along easily grains of sand about the size of small shot, but during hurricanes stones weighing 2 to 3 lb. have been known to be moved. It is recorded that after a violent windstorm stones from 1 to 1½ in. in diameter were observed to fall, after having travelled a distance of over 90 miles. The small sand-grains and fine dust driven along before the wind act on the solid rocks over which they pass in the same way as the sand-blast used for engraving on, and drilling holes in, glass. Rock-masses and isolated boulders lying on the desert are ground, scratched, and sometimes polished like a mirror, so that the whole surface looks as if it had been varnished. The effects produced by the abrasion of wind-borne material are peculiar and are only obtained by its means. As rocks are seldom of uniform hardness, the "sand-blast" action affects different parts in different degrees; the soft places are picked out and worn into curious channels and hollows, leaving the harder portions standing in relief. In this way the most fantastic forms are frequently obtained.

ZEUGEN.—A large part of the African desert is formed of horizontal layers of hard and soft rocks, and the surface-level of the desert is usually determined by a hard layer which protects the softer beds underneath. These horizontal beds are traversed by cracks and joints, which divide up the surface into a network. The sand-grains acting along these cracks gradually wear away their edges and widen them, thus producing deep fissures, spreading in all directions and cutting up the surface into a number of isolated columns of soft rock, capped by a harder layer. According to Walther a new weathering agent then comes into play, the mode of action of which is instructive as showing how great results can be produced by a comparatively insignificant cause if allowed to

act for a sufficient length of time. On account of the rapid cooling of the surface by the excessive radiation at night, there is a heavy fall of dew, which during the day remains longer in the shady places than in those exposed to the sun. The water attacks the solid rock, dissolving it slightly and loosening its grains. When the dew disappears the loose particles are blown away by the wind, thus increasing the size of the shaded area and enabling a greater amount of dew to remain on it next time. This action goes on increasing until large hollows are worn away underneath the hard layer forming the tops of the columns. As the effect of dew is necessarily greatest in the shadow of the protecting cap, and decreases away from it, a characteristic form is imparted to these columns (fig. 9). They are known by the German name of ZEUGEN. In time the cap becomes undermined and falls, leaving the soft support at the mercy of the destructive sand-blast. It is then soon reduced to the level of the next hard bed, and when the other pillars have been removed in the same manner the lower bed becomes the surface of the desert, and the processes sketched above begin over again.

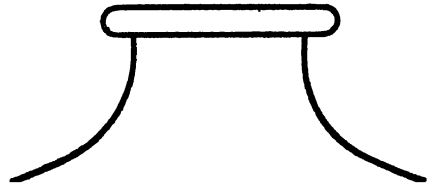


Fig. 9.—Ideal Section of a "Zeuge"

The effect of hard and soft rocks is produced in the Egyptian desert in quite another way. A hard brown crust of oxides of iron and manganese forms over the surface of the rocks regardless of their nature. It also covers cliffs and projecting masses, from which it frequently peels in strips from some cause as yet unexplained. The exposed parts are immediately attacked by the wind, and window-like recesses are carved out; the rock beneath is hollowed by the combined action of wind and dew into large cavities, which frequently unite with one another behind the crust. A similar effect is produced on the outstanding pillars or "Zeugen", when the peeling of the brown crust in patches allows the wind to erode them into the most grotesque patterns.

The effect of the wind-borne grains on pebbles lying on the desert is to wear flat faces or facets on them, and as the wind blows from one quarter for a long period, these facets have a constant direction; a change of the wind gives rise to new facets. The result, in general, is to develop three of these, which meet in an obtuse angle.

DESERT SAND-GRAINS.—A peculiarity of desert sands is their very high degree of rounding, brought about by the continual buffeting to which they are subjected against one another and against the surface over which they pass. As a rule they are almost spherical, and on

account of the sorting action of wind are of uniform size. These characteristics are conveyed in the term "millet-seed" sands which has been applied to them.

At rare intervals, violent storms accompanied by heavy rains pass over the desert, when all the gullies and channels on the bordering slopes are swept by water which floods the plains at the foot. These floods are remarkable for their sudden appearance and for their violence. A great deal of water transportation takes place on those occasions, and the corrasion must be considerable, for the blocks carried down are often of enormous size, and are usually well rounded. The sand, gravel, and coarse material are distributed in sheets on the plain, and such of it as is of the proper size is picked up and borne along by the wind when the rains have passed. The water which flows over the desert disappears partly by evaporation and partly by soaking into the ground.

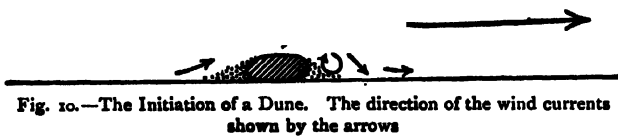


Fig. 10.—The Initiation of a Dune. The direction of the wind currents shown by the arrows

It is known that a great deal of water exists under many deserts, which can be reached by boring.

This method is pursued

along the northern margin of the Sahara, and, in consequence of the supply of water thus obtained, a great deal of land has been reclaimed for cultivation.

DEPOSITS IN DESERT AREAS.—The deposits around the borders of the desert have been already mentioned; in addition to these are the accumulations of material by wind agency. These are known as **DUNES**, and are highly characteristic of the agent which produces them. Any object, such as a stone or a plant, on the surface of the desert in the path of the wind serves to start a dune, but in some cases they may arise without any of these. The wind carries along grains of sand of various sizes up to a certain limit; a slight lessening of its force causes it to drop the heavier ones; these act as obstacles to the lighter grains, which begin to heap around them. As soon as this happens the formation of dunes begins. The sand is driven up the slope on the windward side and blown over the top; on the leeward side there is some shelter, and a wind eddy or swirl is caused. Many of the grains blown over the top are carried down by the swirl, and some of them are left where they fall; but others are picked up by the upward swirl and carried into the wind current again (fig. 10). A swirl of this kind can often be observed in a dusty lane when a high wind is blowing across it. The dust does not accumulate on the windward but on the leeward hedge, as is shown

in illustration (fig. 11). When a dune has been started it continues to grow vertically and horizontally at right angles to the direction of the wind. The eddy on the lee side is greater where the dune is highest, so that the excavation on that side is greater, or, in other words, less material is allowed to settle there than where the dune is lower. Consequently the ends of the dunes are pushed forward more rapidly than the centre, and a crescent is formed with the horns pointing forward. As a rule these crescents grow end to end, and there is generally a

parallel series in front and another behind. The windward slope is always less than the leeward, and a succession of dunes therefore presents a profile somewhat as shown in the figure (fig. 12). Variation in the direction and force of the wind causes the dunes to shift or migrate, and very complicated

forms generally result from this cause. This migration of dunes is a phenomenon often observed in desert areas, though it is not confined to them. When the wind blows from the west in the Desert of Atacama, which stands at a high altitude on the borders of Bolivia and the Argentine Republic, the sand is driven on to the eastern slopes of the Andes in such quantity that it descends into some of the valleys on that side like great rivers, grinding and polishing the rocks over which it passes.

DESERT LAKES.—Although on a large scale the surface of a desert may be a plain, yet there are usually hollows in which pools of water collect at certain seasons of the year.

In some cases these may be of great extent, and the water may persist throughout the dry intervals. Material is carried into these pools by water, and some is blown in by

the wind. Water carries matter in suspension as well as in solution; the suspended matter gradually settles and accumulates on the bottom. During the dry spells the quantity of water is much diminished, and great stretches of fine mud are exposed round the margins. The heat of the sun in drying the mud causes it to shrink, and a system of cracks is developed which is rather characteristic. The tracks of animals in search of water are imprinted on the partially dried mud, and if a shower of rain falls the drops produce a pitting of the surface. By the evaporation of the water the total amount of dissolved matter increases gradually,

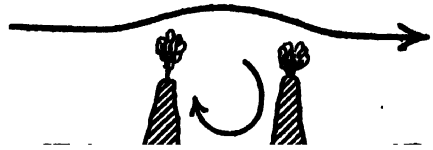


Fig. 11.—Diagram illustrating the "Swirl" in a Narrow Lane. The arrows indicate the direction of the wind-currents



Fig. 12.—Ideal Profile of a Series of Dunes. The arrow indicates the direction of the prevailing wind

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and after a sufficiently long period may accumulate to such an extent that precipitation occurs. In this way deposits of common salt, gypsum, and other chemical salts are frequently formed in desert areas. These facts are mentioned here because, as we shall see later, similar phenomena have been observed in some of our ancient deposits, and hence a clue is obtained as to the climatic conditions under which those deposits were formed.

DENUDATION IN REGIONS OF GREAT COLD

Around both poles of the earth at the present day there are extensive tracts where the mean annual temperature does not exceed that of the freezing-point of water (32° F.), so that the snow and ice which accumulate during the long winters are not thawed away by the heat of the short summers. These conditions also obtain at great heights in various latitudes, even on or near the Equator, as, for example, in the Andes of South America, and Ruwenzori, or the Mountains of the Moon in Central Africa.

SNOW LINE.—Places where the summer melting of snows just keeps pace with the fall during the winters are said to be on the SNOW LINE. In high northern and southern latitudes the snow line descends to sea-level, but it rises towards the Equator to a height of about 16,000 ft. In Norway it stands at about 5000 ft., in the Alps at about 9000 ft., while in the Himalayas it descends 3000 to 4000 ft. lower on the south than on the north side. It does not follow that the whole ground above the snow line is occupied by snow, for the slopes are frequently too steep to allow of its resting on them; and again, the fine powdery condition of the snow which falls in those regions renders it liable to be blown off the exposed places into gullies and sheltered hollows.

FROST.—In cold regions weathering is brought about by the action of frost. It is well known that a given volume of water increases in bulk on freezing, and diminishes by a corresponding amount on thawing. During warm weather the water insinuates itself into cracks and crevices in the rocks, and when the temperature falls to freezing-point the increase in volume forces the walls of the crevices apart. As this action is repeated the crevice grows wider and wider, until the rock-mass on one side or the other loses its balance and topples over. The result is very similar to that produced by unequal contraction and expansion on rocks in a desert, but in cold regions the action does not depend so much upon extremes of temperature as upon a change of a few degrees

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...ing of the rocks would be much less if the temperature varied between 35° F. and 45° F., or between 15° F. and 25° F., than if it varied between 25° F. and 35° F., as in the last case freezing or melting would take place every time the temperature of 32° F. was crossed. The effect is accelerated if planes of weakness exist in the rocks, either as joints, bedding-planes, or cleavage-planes (see pages 100, 145), and is most marked on the crest of mountain ranges where a thick mantle of snow



Fig. 13.--The Pulpit Rock, Scilly, showing the accumulation of weathered granite (Geol. Survey Photo.)

cannot accumulate on account of the steep slopes or the absence of precipitation. Also, under such conditions transportation by ice or running water (see below) is often ineffective, and the shattered rocks accumulate in immense heaps until the mountain crest becomes buried under its own ruins. This is especially illustrated on the high central chain which traverses the north of Tibet. The illustration (fig. 13) shows a somewhat similar phenomenon on one of the granite tors in the Scilly Isles.

TRANSPORTATION is mainly effected by gravitation, wind, and ice; the last is, however, by far the most important, and must be treated at some length. Some of the fragments dislodged in the higher parts of a mountain range fall down the slopes, and, with a constantly increasing number of others loosened and dislodged in their progress, shower down

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into the valleys, encumbering them with angular masses of rock of all sizes. In the valleys bordering the Tibetan range mentioned above there is now very little transportation by ice or running water, and the valleys are being gradually filled up by material of this kind. Such valleys have a cross section unlike that of ordinary valleys, and are known as PAMIRS. Under certain conditions wind may become an effective agent of transportation, especially when the amount of precipitation is small.

ICE AND SNOW.—The quantity of material transported by wind and gravitation bears, however, but a small proportion to that carried by ice and snow. Above the snow line so much of the fall of one season as is not wasted by thawing or evaporation remains on the ground until it is covered over by the next season's contribution, and thus the falls of successive years accumulate to form SNOWFIELDS. On account of the prevailing cold the snow as it falls is in a fine powdery condition, but in some way not fully understood it soon passes into a granular mass full of air-bubbles; it is then known as NÉVÉ, or FIRN, which gradually passes over into fairly hard but porous ice. The accumulation of successive years sets up great pressure at certain points in the frozen mass; when it exceeds a certain limit the whole mass begins to move away from the region of great pressure.

GLACIERS.—Once set in motion, the ice continues to move so long as the pressure is kept up by fresh accessions of snow; its function as a carrier or transporting agent then begins. Snowfields vary in size according to the altitude and latitude. In low latitudes they are usually small, but those around the poles are of enormous extent. The area of the North Polar field has been estimated at 300,000 to 400,000 sq. miles, or about 500 times that of the snowfields of Switzerland; while around the South Pole there is believed to exist an area of 3,000,000 to 4,000,000 sq. miles of snow and ice. In low latitudes, again, the snowfields usually form on the high ground at the heads of valleys, and under the influence of the great pressure the ice finds its outlet down the valleys, giving rise to those "rivers of ice" known as glaciers. Those of the Alps are well known, and have been exhaustively studied, and valley-glaciers originating in this manner, wherever they may occur, are known as *Alpine glaciers*. In higher latitudes it sometimes happens that the glaciers do not end off in the valleys, but descend to the low ground at the foot of the mountains, where they unite to form one large glacier. From their mode of occurrence at the foot of the mountains they are known as *Piedmont glaciers*. Of such the best known is the Malaspina Glacier of Alaska.

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ICE SHEETS.—In all higher latitudes the snows are so abundant as to bury all the land features; the surface of the land is thus covered of the form of the ground underneath, and movement of ice takes place not from the highest points of the land, but from the places where the fall of snow is greatest. These places may in some cases be over the sea, and there may be more than one centre from which the ice radiates. An extensive cover of this kind is termed an **ICE SHEET**. We cannot proceed briefly to describe these various types and their action, but will begin by them, beginning with the simplest kind.

ALPINE GLACIERS.—The slopes above an Alpine glacier are free from snow and bare of vegetation, consequently the rocks which form them suffer severely from frost action, and are shattered and split into angular masses of all sizes. Many of these tumble on to the margins of the glacier, and as the latter moves down the valley the debris encumbering its sides continues to increase. The material carried by glacier is known as **MORAINE**, to which different names are applied according to its position in or upon the glacier. That which collects at the sides in the manner indicated is known as **MARGINAL MORAINE**. As the ice-stream travels slowly down the valley it is joined by other streams from neighbouring valleys; where they meet, one of the marginal moraines of the tributary glacier unites with that marginal moraine of the main valley which lies nearest to it to form a single moraine occupying a strip along the middle, and known as a **MEDIAL MORAINE**, the others then become the marginal moraines of the new glacier. This process is repeated each time the glacier receives reinforcements from tributaries, until there may be several lines of medial moraines. These do not remain for long as narrow strips on the middle of the glacier, but begin to spread and to wander over the surface. If the distance is not too great, the material from two medial moraines mingles, and in the lower parts of the valley it is often difficult to distinguish the lines of moraines amid the litter of rubbish which cumbers the surface of the ice.

The mode of wandering of moraine material is interesting, and takes place somewhat as follows: During the day, especially in summer, thawing is active at the surface of the glacier, and if a large stone lies on the ice it protects the part immediately underneath from the heat of the sun. Therefore, while the ice all round is thawed quickly, that underneath the stone scarcely suffers, and remains behind as a pedestal on which the stone is poised. Thawing of the pedestal proceeds very slowly on the side away from the sun, but more quickly on the other side. The stone is therefore undermined on the sunny side and topples over, leaving

unprotected the little ice mound, which then vanishes quickly, and the process is repeated under the stone in its new position. In this manner stones travel quite long distances along the surface of the glacier. The case is altogether different if the stone is a thin flat one. Dark-coloured substances absorb or take up heat more readily than white or light-coloured ones; therefore a stone heats more quickly than ice when exposed to the sun's rays. If the stone is thin this heat is passed on to the ice underneath, which therefore melts more quickly than the surrounding portions, and the stone sinks until it is too deep to be reached by the rays of the sun. Even little heaps of dust will set up this action, and holes a foot or two in depth made in this way are of frequent occurrence on some glaciers, sometimes proving a trap for the unwary pedestrian.

Comparatively little material finds its way into the glacier by these means as compared with that borne in by streams. When the ice thaws, the surface of the glacier is occupied by a great volume of water which runs along the margin or finds its way inside along the numerous cracks or fissures known as CREVASSES, which traverse the ice often to great depths. The stream of water falling into one of these fissures carries with it from the surface dirt and stones, which it whirls round and round until it succeeds in grinding a hole through the ice and finding its way to the bottom. These holes in the ice into which streams of water pour are known as "glacier mills". The mill-action sometimes goes on in the solid rock underneath, and round holes worn in this way are of frequent occurrence in valleys which have been recently occupied by glaciers. Sometimes the stream, before reaching the bottom, finds a channel in the ice and follows it, depositing much of its suspended material in its course. Such material and all other which is carried in the ice is said to be ENGLACIAL or INTRAGLACIAL. Some is also pushed along underneath the glacier, and is known as GROUND MORaine.

The average temperature down a valley is higher than at the head, so that the ice wastes by thawing and evaporation the more quickly the farther down it moves. A part of the valley is ultimately reached where the waste just keeps pace with the supply, and the glacier can get no farther. All the material which was carried in, under, or upon the ice is then dropped as a TERMINAL MORaine. This follows the form of the snout of the glacier, which protrudes farther in the middle than at the sides; a crescentic ridge therefore results, which stretches across the valley.

EROSION BY GLACIERS.—In addition to their actual carrying capacity, glaciers act as powerful agents of destruction in another way. The great

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weight of ice moving down the valley presses heavily on the bottom, and grinds away the surface underneath. This action is assisted by the stones which have worked their way through the ice, and which, held in the frozen mass, plough their way along, scoring and grooving the solid rock; the stones themselves suffer a similar treatment, and are slowly ground away. Projecting pieces of rock on the sides of the valley are often wrenched off and borne away, tearing and scratching the solid rock along their course. Those valleys which have in recent times had glaciers have a character quite their own. The bottom and sides, to the limit reached by the ice, present smooth, worn outlines when viewed looking down the valley, but a more rugged aspect when viewed from the opposite direction. Again, faces of bare rock, rounded, scratched, grooved, and sometimes highly polished, testify to the intense abrasion which they have undergone; they are known as *ROCHES MOUTONNÉES* (see fig. 40, p. 3, vol II).

Glaciated valleys have a broad U-shaped cross section, which to the experienced eye at once discloses the agency which shaped them. Considerable differences of opinion still exist as to the limit of possibility of abrasion by ice. Some have claimed that deep lakes of great extent have been scooped out of the rock by this means, and that wide valleys have been carved to the depth of hundreds of feet in some regions by the same agency. Others maintain that the whole power of a glacier is taken up in carrying its load, and all that the ice can do is to remove a certain amount of loose material from the surface of the land and slightly polish the rocks underneath. The truth probably lies in most cases between these extreme views. It seems certain that some lakes do lie in basins scooped out of the solid rock, though their number is much smaller than it was at one time believed to be; further, there is no doubt that in some cases glaciers have left a very lasting proof of their efficiency as agents of erosion, but in others which were thought to afford similar proof an explanation has been found in circumstances that had escaped recognition.

GLACIER MOTION.—The rate of movement at various points of a glacier has been determined by planting a series of stakes across it, and noting their positions from time to time. In this way it has been ascertained that the central part moves faster than the sides, which are held back by friction, and for a like reason the upper layers move faster than the lower ones. The motion is greater in summer than in winter, so that it depends in some way on temperature. Further, it is conditioned by the slope or gradient of the *upper* surface of the ice, being greater for a steep than for a low gradient; and finally it depends on the thickness of the

ice and upon the load, the last having a retarding effect, as might be expected. With regard to the actual rate of motion it has been found to vary within rather wide limits. The mean rate for the best-studied Swiss glaciers is from 1 to 4 ft. per day.

From underneath the end of an Alpine glacier there emerges a turbulent stream, thick and muddy with the sediment derived from the grinding of the rocks within and under the ice. This sediment is known as "glacial flour" or "glacial meal", and is so extremely fine that it settles with difficulty in still water.

PIEDMONT GLACIERS are best known in Alaska, where several glaciers of the Alpine type descending from the Mount St. Elias range unite at the foot to form the single Malaspina glacier. This type presents certain peculiarities which mark it out from the other types. In the first place its motion is exceedingly small, and many parts of it, especially near the margin, are at rest, or in the condition of dead or stagnant ice; also it gives origin to numerous streams which flow along the surface of the ice and over the plain beyond, covering that with a vast sheet of pebbles and sand derived from the moraines. In places the ice has been stagnant for so long a period that it has been buried underneath these spreads of detritus, which now bear abundant vegetation and even forests of tall trees. When the ice finally melts, the whole surface, carrying with it its vegetable growth, must subside bodily.

CONTINENTAL GLACIERS OR ICE-SHEETS.—These are found around both poles of the earth. The Arctic ice- and snow-fields have been more thoroughly explored than those of the Antarctic, but even in the better-known region the knowledge hitherto gained has only touched the fringe of that huge area of desolation. This is still more the case in the icy wastes around the South Pole, which are estimated to have an extent of 3,000,000 to 4,000,000 sq. miles. This estimate is itself of necessity vague from lack of information as to the limits of the ice; but when compared with the 300,000 to 400,000 sq. miles of the North Polar ice-sheet, about which there is still so much to know, the magnitude of our ignorance concerning the giant southern field can be to some extent realized.

GREENLAND ICE-SHEET.—The Arctic ice-sheet has been studied chiefly near its southern margin in Greenland and Spitzbergen. In the south of Greenland there is a fringe of land which is free from ice for the greater part of the year, and supports a scanty population. Farther inland the valleys are occupied by glaciers of the ordinary Alpine type; while still higher up the thickness of ice increases, covering more and more of the ridges between the valleys, until finally all but the highest peaks disappear

underneath the mantle of ice and snow. The points which project above the sheet are known by the natives as *nunatakk* (a term which has been received into current glacial literature under the form NUNATAKS). In the inland parts the ice-sheet covers everything, and appears to rise to considerable heights in the unexplored regions in the centre of Greenland.

MOVEMENT OF ICE-SHEET.—An ice-sheet behaves in many respects very differently from Alpine glaciers. The latter are confined, as it were in grooves, by the sides of the valleys, and are forced to move along those grooves. This must be true to a certain extent of the lower layers of an ice-sheet; but the upper layers, which are far above all land features, are free to move in any direction independently of those. Thus, it is possible for the upper and lower layers of an ice-sheet to move in different directions. An important consequence of the independence of an ice-sheet of land features is that motion does not necessarily take place away from the points where the land is highest, but from the points where the ice is thickest, and therefore heaviest. These are the points where the snow-fall is greatest, but are not of necessity the coldest points, being determined by various climatic conditions in the same way that the places of greatest rainfall are determined in warmer regions.

TRANSPORTATION BY ICE-SHEETS.—The surface of an ice-sheet inland is formed of clean ice and snow, as there are no rocks exposed above it to cumber it with debris; but where the nunataks begin to appear they give rise to moraines similar to those on an Alpine glacier. The load of an ice-sheet is mainly carried by the lower layers of ice, or pushed along underneath, and is therefore known as a SUBGLACIAL load. On account of the irregularity of the floor over which the sheet moves, and in other ways not yet sufficiently explained, a great deal of material derived from underneath penetrates well within the ice, forming an ENGLACIAL load. Another feature of importance is the elaborate river-system which is often developed inside the ice. These streams carry and distribute their deposits just as ordinary streams do, and if the ice were to melt away, the stream deposits would be dropped on to the land surface immediately underneath. As the streams within the ice are obviously independent of the shape of the land, the deposits would cross hill and dale alike. Lines and ridges of deposits of this kind have been observed in many districts which are known to have undergone glaciation. They have been given various names, such as ÅSAR (pronounced osar) in Scandinavia, ESKERS in Scotland, and KAMES in Ireland. In high latitudes the glaciers frequently end off, not in a tapering snout, but in a vertical or overhanging cliff, which is known as a "Chinese wall". It is characteristic of

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~~glaciers which are at present advancing; those which terminate in the margin of ordinary Alpine glaciers are receding.~~

UPHILL MOVEMENT—ICEBERGS.—Observations carried on near the margins of the ice in Greenland and Spitzbergen have shown that glaciers can move uphill and carry material to considerable heights. This takes place by shearing or slipping of the layers of ice over one another, due to the great weight pushing from behind. Marine shells have been found in moraine material at a height of 400 ft. above sea level, and must have reached that position by an uphill movement of the ice. In the same manner contortion of the frozen moraine material and of the underlying strata are produced. The importance of these observations will appear when the glaciation of former times is considered. The deposits of the Arctic glaciers are somewhat similar in character to those of Alpine glaciers, but inasmuch as many of them descend to sea level, other deposits are formed in the sea by the melting of icebergs and floes, some of which may be carried to great distances away from the parent ice mass. The packing and stranding of floes along coast-lines causes the grooving and polishing of hard rocks and the contortion of softer strata.

CHAPTER II

DENUDATION IN TEMPERATE REGIONS— DEPOSITION

DENUDATION IN TEMPERATE REGIONS

We have already considered the processes of denudation under extreme climatic conditions, and have seen that on the whole they are characterized by their simplicity. In temperate regions this simplicity is largely lost sight of, for the number of agents of weathering and transportation is much greater, and their action is complicated by causes which were absent in regions of extremes of temperature. The most important of these is the presence of vegetation, which under some conditions actively assists weathering and transportation, and under other conditions retards one or both of these processes. Vegetation also exerts an important influence upon climate, and as a consequence upon the direct operation of denudation.

WEATHERING.—Extremes of heat produce results similar in kind

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though not so dense as in the tropics, it serves as a protection to the soil and thus retards the effect that would otherwise be produced by the frost.

FROST ACTION during the winter is particularly vigorous in shattering the rocks, and indeed is the most effective agent of weathering; its action is to some extent retarded by vegetation, though in most instances it is accelerated.

VEGETATION.—The weathering action of vegetation is of a twofold nature, the one a direct, the other an indirect effect. It is well known that abundant vegetation, especially of trees and dense shrubs, increases the rainfall of a district, and consequently the rate of weathering and denudation. This is the indirect effect. The roots of plants, in penetrating into the soil, loosen and disintegrate it; further, they are often insinuated into cracks and fissures in the rocks, and as they grow tend to force them apart. This of itself slowly breaks up the rocks, but in addition it allows water to enter the cracks, so that on freezing it enlarges them still more.

Another agent of weathering, which is much more pronounced in temperate regions, is CHEMICAL SOLUTION. Rainwater, which carries certain gases in solution, slowly dissolves the rocks and carries away the material. Its solvent effect is greatly increased by the organic acids which it takes up in passing through decayed vegetation. Certain kinds of rocks rich in carbonate of lime are removed in large quantities in this way.

AGENTS OF TRANSPORTATION.—Gravity acts in the same way as in other regions. Wind is less effective on account of the protection afforded by plants, but it serves to remove much fine material from the surface of the land and to blow it into streams or directly into the sea. Glaciers do not occur, but somewhat similar results are produced on a small scale in winter by the sliding and slipping of snow on slopes, while, locally, landslips produce very destructive effects.

RUNNING WATER.—But the distinguishing feature of denudation in temperate regions is the predominant part played by running water in transportation and corrosion. The topography is almost entirely determined by this agent, and the kind of surface formed is, in its main characteristics, distinct from that produced by wind or by ice. If we consider any river system with which we are familiar, we perceive that it is made up of a branching series of channels of varying width, length, and depth, each carrying a stream of water which bears some relation to its size. Each stream, whether it be a runnel on a hillside or a great body of

water like the Mississippi, takes its part according to its capacity in removing material from the surface of the land and depositing it at a lower level either on the bottom of a valley, in a lake, or in the sea. It is convenient to speak of the sediment which a current of water carries in suspension or pushes along the bottom as the *load*. The friction of the particles against the bed of the stream wears it down by corrasion, so that the action of a stream consists of two parts: (1) carrying its load; (2) wearing away its channel. It is important to remember that the power of a stream at a given point and time is a fixed quantity depending on certain conditions which will be discussed below; so long as these conditions do not vary its power cannot be increased or diminished. Now, if a part of the power is taken up in carrying its load, less must be available for wearing down its channel; on the other hand, a stream which is rapidly wearing away its bed cannot carry as large a load as a similar stream which is not doing work of this kind. This point is frequently lost sight of, and one is tempted to imagine that a river in flood, thick with sediment, must be wearing down its channel at a great rate; so far, however, is this from being so that in many cases the stream is actually forced to drop part of its load from inability to carry it, and is therefore building up its bed instead of wearing it away.

The POWER OF A STREAM increases with its volume and its velocity; the volume varies, of course, from day to day and from season to season according to the rainfall; the velocity also increases with the volume as well as with the fall or gradient; it depends in addition on the cross section of the channel, the nature of the channel whether smooth or rough, and on the load, a very considerable part of which is not carried in suspension, but is pushed or rolled along the bottom. A stream carries also what may be termed an invisible load, consisting of substances in solution.

RATE OF TRANSPORTATION BY RIVERS.—A few instances of the rate at which streams and rivers are shifting material from the land to the sea will illustrate the prodigious amount of work done by running water—the most effective agent of transportation.

The Mississippi drains an area of about a million and a quarter square miles, and discharges on an average 600,000 cu. ft. of water per second into the Gulf of Mexico. Careful observations have shown that the weight of the sediment carried in suspension bears to the weight of water the proportion of $\frac{1}{1800}$, while the amount pushed or rolled along the bottom is $\frac{1}{1800}$ of the weight of water, and the amount in solution is about $\frac{1}{8000}$. Taking the dissolved material, this mighty stream re-

moves every year nearly 113,000,000 tons of the land in this way alone; this lowers the height of the drainage area at the rate of 1 ft. in 25,000 years. If we consider the whole of the material this river is reducing the average height of its drainage area at the rate of 1 ft. in about 4000 years. The average results obtained from the nineteen principal rivers of the globe correspond almost exactly with the figures given for the Mississippi. The average height of the land all over the globe has been estimated at about 2350 ft., and if the rate of denudation obtained above be assumed to hold for the whole surface, a simple calculation shows that all the land would be reduced to sea level in about 9,500,000 years by this cause alone. But the material thus thrown down on the bottom of the sea causes a corresponding submergence of the land. If this process be taken into account, this the period necessary for the disappearance of all land is reduced to 7,000,000 years. Of course, running water is not equally effective all the world over; as we have seen, it is almost ineffective over wide areas but its place is there taken by other agents, while marine denudation along the coast lines, which materially assists the action of streams and rivers, has been left out of account. As there is abundant evidence that even the larger figure is but a very small fraction of the length of time that has elapsed since the globe became habitable to organic life, it follows that unless some active process has been at work producing new land to replace that worn away by denudation the sea would have covered the whole surface of the globe long ages ago. In a later chapter the renovation of the land area will be considered, but before going on to this question it is necessary to enquire what becomes of all the land when it has once reached the ocean. We shall see that after a sojourn there of greater or lesser duration some of it is destined to become dry land once more, and be once more subjected to the processes of denudation.

MARINE DENUDATION.—The part taken by the sea in the denudation of coast lines must receive brief consideration, for, although in comparison with streams and rivers it is a minor agent, yet in course of time important results are produced by its means. Its functions are twofold, viz. removing and distributing materials which are supplied directly by weathering along the coast or are carried in by rivers, and wearing away by friction the rocks within its reach.

The power of the sea is due, in the first place, to the tides, and in the second place to the action of wind in raising waves upon its surface; its destructive effect is due chiefly to the latter action.

REMOVAL AND DISTRIBUTION OF WASTE.—Weathering along the coast above the reach of the waves produces angular fragments of various kinds of rocks, which slip or fall into the sea, where they are subjected to a constant movement to and fro along the beach; their angles are knocked off by friction against the ground or against one another, and they are gradually reduced in size. In addition, there is, along most coasts, a drift of water in a certain direction, which depends among other things on the shape of the coast and the direction of the prevailing wind. There is, therefore, a tendency for the material to be transported and distributed along the coast; the constant wear which this entails reduces all but the hardest rocks to the state of fine sand or mud according to their original constitution. Such fine material can be carried in suspension by marine currents of moderate force, and, together with that brought in by rivers, is transported often to great distances from the source and dropped where the currents diminish in force. As the power of the waves is usually greatest where the water is shallow, and diminishes towards the deep, the coarse pebbles and sand are found near the coast-line, the fine sands farther out to sea, while the muds and clays occur at considerable distances from the shore, and in comparatively deep water.

DESTRUCTIVE ACTION.—With regard to the actual destruction effected by this agency, it has been estimated that the amount of material thus removed from the land every year is only about a twentieth part of that carried by rivers. The features produced along the sea margin have, however, peculiarities of their own, which determine to a no small degree the type of scenery which gives character to that part of the earth's surface.

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LITTORAL, SHALLOW-WATER, AND DEEP-SEA DEPOSITS.—When the rivers and streams carrying sediment from the land reach the sea, their velocity is checked, and they are forced to drop part of their load. The coarser material is usually dropped in their estuaries, or near their mouths, while the finer is carried farther out to sea. As we have seen, wave action produces similar material around the coasts, which is also distributed according to the velocity of the water. It follows that, as a rule, near the land, deposits of boulders, gravel, and coarse sand are laid down, while farther seaward the grains become gradually smaller, and the deposits grade through fine sands to muds and clays. Marine deposits formed around the margins of continents may therefore be divided into (1) littoral deposits, accumulated between high- and low-water marks;

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(2) shallow-water deposits, which extend on an average from low-water mark to a depth of about 100 fathoms. Beyond this limit the sea floor descends somewhat abruptly to considerable depths, where are formed what are known as deep-sea deposits. The greater part of the latter consists of the remains of organisms, but towards the zone of shallow water there is a gradually increasing admixture of mud and clay derived from the land.

EXTENT OF MARINE DEPOSITS.—According to Murray, the length of the coast lines of the world is about 125,000 miles, and, if the littoral zone be assumed to have an average width of $\frac{1}{2}$ mile, the area on which coarse material is laid down is about 62,500 sq. miles. Shallow-water deposits have been estimated to cover an area of about 10,000,000 sq. miles, while the deep-sea sediments cover considerably more than one-half of the superficies of the globe.

COMPOSITIONS OF LITTORAL AND SHALLOW-WATER DEPOSITS.—In both shallow-water and littoral deposits the remains of animals which lived on the bottom, and of others which floated near the surface, are buried, and if the deposits be upraised at a later period to form land those remains indicate the nature of the animals which inhabited the sea at those depths. The parts that resist decay are the hard parts, such as the skeletons and shells, which are formed chiefly of carbonates and phosphates of lime, derived from the salts carried down in solution by rivers. It is only exceptionally, however, that the organic remains in these zones bear any considerable proportion to the amount of sediment mechanically derived from the land.

DEEP-SEA DEPOSITS—OOZES.—In the deeper parts of the ocean, however, it is quite otherwise, for there the quantity of mechanical sediment is extremely small, and the deposits are made up almost exclusively of the remains of organisms. In many parts of the warmer seas, islands occur which are built up of the remains of generations of dead corals; the bottom of the ocean around these islands is covered by a fine white sand and mud derived from the breaking up of the coralline growth by wave action. Such deposits, from the nature of their origin, are local and only of limited extent. The largest areas of this kind occur in the Caribbean Sea and the Gulf of Mexico, off the north and north-west coasts of Australia, and towards the centre of the Pacific and Indian Oceans. Other deep-sea deposits are known as OOZES, and the various kinds are distinguished according to the nature of the organisms which gave rise to them. The most important of these is *Globigerina ooze*, formed chiefly of the tests of *Globigerina* and other members of the

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ocean floor, it is estimated, to cover an area of nearly 50,000,000 sq. miles. It is characterized by a high percentage of carbonates of lime and magnesia, but this diminishes considerably at great depths, owing, it is supposed, to solution of the carbonates by sea water under the enormous pressures which obtain at those depths. Mineral particles are not altogether absent, but the grains are extremely minute, and are probably derived from volcanic dust settling down in the ocean. Another kind—*Pteropod ooze*—is chiefly confined to submarine ridges in the Atlantic at depths not exceeding 1400 fathoms. It is formed almost entirely of the tests of *Pteropods* and *Heteropods*. The animals whose remains go to the formation of these deposits live in the surface waters of the regions where they occur, and on their death their tests shower down to the bottom. The *Diatom* and *Radiolarian oozes* are characterized by much less carbonate of lime and a greater proportion of silica, and are formed mainly of the remains of animals (radiolaria) and minute plants (diatoms) whose tests are siliceous. *Diatom ooze* is almost confined to the southern Pacific and Antarctic Ocean, where it occupies an area estimated at nearly 11,000,000 sq. miles.

ABYSSAL DEPOSITS—RED CLAY.—In the deepest parts of the ocean there exists an extremely fine-grained red or grey clay, in which are scattered nodules or concretions of iron and manganese oxides. The most interesting feature of this deposit is the extreme slowness at which it is forming. It contains a large number of teeth of sharks and bones of whales, some of which are quite clean, while others are coated with a thick crust of iron and manganese oxides. This crust is itself probably of very slow growth, and the fact that the teeth and bones coated with it have not been covered up shows how slow must be the accession of sediment. Further, some of the sharks' teeth suggest fossil forms, which have been found in Tertiary strata. It is therefore possible that at those great depths the deposits of long ages occur mingled together. Some of the mineral grains are probably of volcanic or meteoric origin.

SEDIMENTARY ROCKS.—It is found that most of the sedimentary rocks forming land areas at the present day are such that they must have been deposited in comparatively shallow water at no great distance from shore lines, so that the deep-sea sediments of modern oceans are of less value in elucidating the past history of the earth than those forming in small depths. It is true that there are large areas of the earth's surface which are made up of rocks derived almost entirely from the remains of marine organisms; but from analogy with the distribution of living organisms it is nearly certain that the former inhabited fairly shallow water. The freedom

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of such deposits from another source, but they are brought about by local causes, probably the influence of ocean currents. It is known that from such causes there are, in tropical seas, at no great distance from coast-lines, areas of shallow water, where very little land sediment is accumulating; the water is always quite clear, and organisms such as corals, which do not thrive in the presence of mud, are giving rise to purely organic deposits.

SHALLOWING RESULTING FROM DEPOSITION.—We are therefore mainly concerned with the study of the fringe of varying width around our coasts, which lies roughly between the high-tide mark and the 100-fathom line. The first effect of the steady deposition of material on the sea floor is to cause a shifting of these limits. As the coarser sediments are spread over a much smaller area than the finer grades, the depth of water near the coast diminishes more rapidly than away from it, and the littoral belt is gradually extended out to sea. The coarse gravel and shingle accompany it, and are therefore accumulated over a strip where previously only coarse or fine sand was formed. In the same manner, but more slowly, the belt of sand is pushed outwards over the muds, and these towards the greater depths. If therefore, after a long phase of sedimentation, one could obtain at any one *place* a section vertically through the whole mass of deposits, there would be found fine sands and muds at the bottom, coarser sand in the middle, and gravel and shingle at the top, in fact a similar succession to what would be found at any one *time* in passing from greater to lesser depths. *

EFFECT OF EARTH MOVEMENTS ON DEPTH OF SEA.—The depth of the sea may vary in other ways; the most important of these is a slow movement by warping or buckling in the crust of the earth. If the movement tends to raise the sea floor the shore fringe passes into dry land and the belt of littoral deposits presses outwards as described above; but if the movement tends to depress the sea floor the changes are reversed—the coarse deposits extend towards the land and finer sediments are deposited vertically over the belt where gravel and shingle were once formed. The column of deposits under these conditions begins with mud at the top, passing down through sand into gravel and shingle. If, as usually happens, alternate rise and fall succeed one another, the sediments vary accordingly, and the vertical column shows alternations in grade from fine to coarse and from coarse to fine.

VARIATION IN DEPOSITS—STRATIFICATION.—Such movements and variations take a long time to be completed, but small changes are in constant operation. During heavy rains the amount and kind of material

erupt down by rivers is different from ordinary times, while at certain seasons the rainfall is greater than at others; and again the rainfall during a certain group of years may be much greater than another group of years. The direction and strength of ocean currents suffer gradual variations according to the direction and force of the wind and other climatic conditions, and the kind of rocks attacked by the rivers may vary from time to time, giving rise to different kinds of sediments. From any or all of these causes the deposits forming at any one place are continually varying in kind and in grade. It is found that different kinds are usually separated by fairly sharp planes of demarcation, so that a vertical section through the accumulated mass shows a series of bands lying horizontally and of varying thicknesses, according to the conditions which prevailed during their formation and the length of time during which any given conditions lasted. These horizontal layers are known as STRATA or BEDS, and the planes of separation are known as STRATIFICATION- or BEDDING-PLANES. Sometimes one or more of these layers is traversed by a large number of horizontal planes dividing it up into thin flakes or laminæ; these are known as LAMINATION-PLANES.

LAW OF SUPERPOSITION.—One most important consequence of the mode of formation of these horizontal layers is that the lower layers must have been formed before the upper, and are therefore older in point of time. This is a fundamental principle of Geology: that strata can be arranged in order of age from observation of the order in which they succeed one another. However simple or obvious such a principle may seem at the present day it was only comparatively recently that it was recognized, and it was even then only accepted gradually as the result of the accumulation of proof. We shall see in the sequel that the various accidents which befall the rocks after they are formed sometimes reverse the apparent order of superposition, so that strata which were deposited later lie underneath those which were formed before them.

LAW OF FOSSIL CONTENTS.—In view of this possibility the principle must be applied with caution, and in some cases must be supplemented by evidence of another kind, which is usually furnished by the organisms inhabiting the sea when the rocks were formed. At their death their remains fell to the bottom and were covered by sediment, and thus locked up, as it were, for future reference. They are known as FOSSILS. As a rule it is only those organisms that are furnished with hard parts, such as shells or skeletons, that leave traces of this kind; other organisms at their death decompose and leave no marks behind them. If we could observe the whole column of sediments formed at any one place, we should

find in general that organic remains were scattered about in it from top to bottom. In dealing with a small thickness probably no difference would be observed between them, but as the thickness increased the difference would be greater the thickness the more marked would be the difference, though in general it would be observed that the fossils were scattered equally. As at any particular time the remains of similar organisms were scattered over considerable areas of the sea floor, it would be found, in comparing this column with that at another place, some distance away, that the organic remains were similar and that they underwent a similar change, in the same order, in passing up through the columns, and that, in fact, the two columns under comparison could be broken up into separate pieces in such a way that the fossils in a given piece of one column could be matched with those of a corresponding piece of the other column, and similarly for the other pieces. This is the foundation of the second great principle underlying Geology, viz. that strata, wherever found, which contain the same organic remains (fossils) were formed at approximately the same time, that is they are said to be of the same age. Reverting to our illustration of the comparison of the columns, if we had made a careful study of one column, noting the organic remains and the order in which they made their appearance, then by means of this principle we could piece together the other column and restore it to its original order, if it were found broken up into fragments which were shuffled up together. It must be noted carefully that before this principle can be applied the organic remains must be studied at a place where there is no doubt of the relative age of the strata; but once this is done for one area the principle can be applied to other areas to determine the original order of superposition when this cannot be directly observed. In this way strata which occur in detached areas can be identified by means of their organic remains with those of a better-known district, and their relative ages can be determined by reference to that district. The two fundamental principles must be used together wherever possible, for it has been found by experience that when either has been applied to the exclusion of the other it has almost invariably led to erroneous results sooner or later. At one time there was a tendency to treat them apart; one group of geologists trusted in the relative order of superposition and disregarded the evidence of the included organisms, especially when it clashed with that of the apparent order; while another group contented themselves with collecting and describing the organic remains without concerning themselves with the order of superposition of the rocks from which they were derived. At the present day most geologists endeavour to combine the two principles.

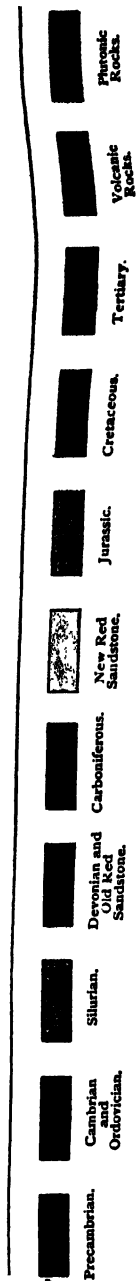
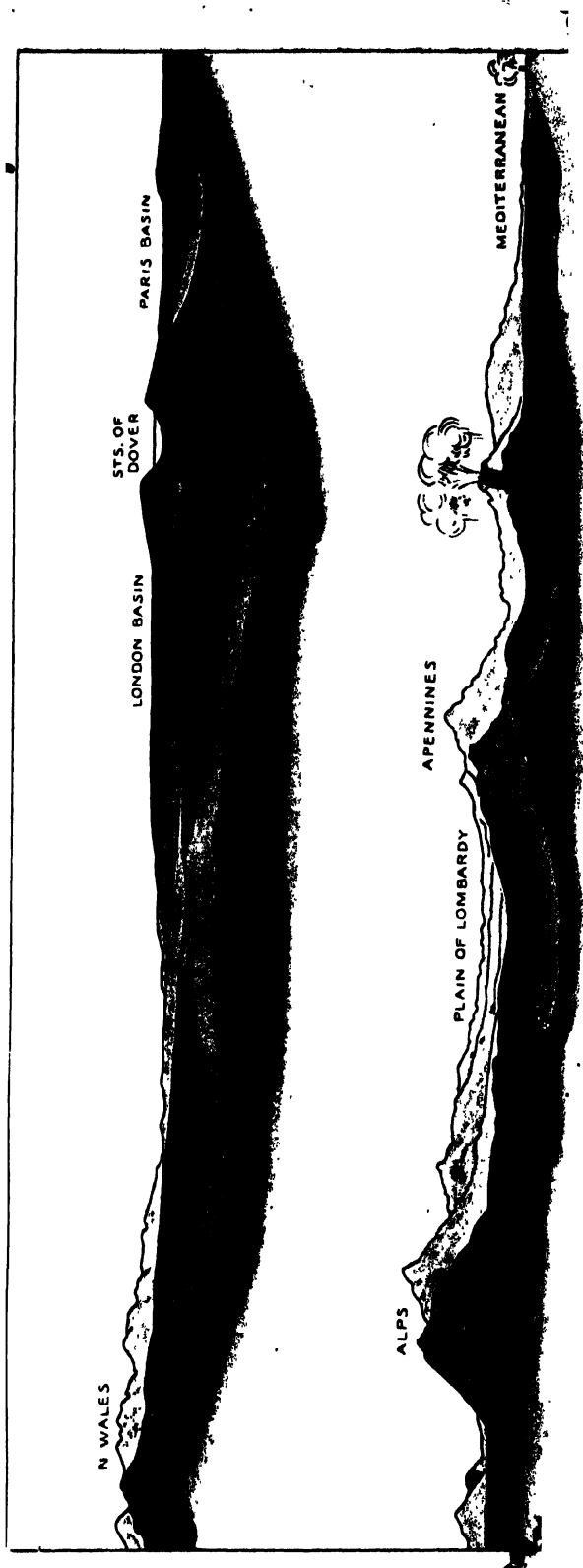
CONSOLIDATION OF DEPOSITS.—We have now traced the materials of denudation from the solid rocks of the land area to their resting place on the ocean floor, where in course of time they undergo certain slight changes in the direction of hardening and compacting the loose particles into more solid masses. The increasing pressure of the accumulated body of sediment contributes to this, while the movement of water among the grains dissolves certain constituents from one part and deposits them in another; mineral substances in solution are also carried in from the sea waters and deposited around or between the grains, which in this way become compacted into more or less solid rocks. The chief cementing substances are carbonate of lime, carbonates and hydrates of iron, and silica, all of which are soluble in water to a slight degree under ordinary conditions, but their solubility is probably increased by pressure. Under certain conditions there is a tendency for mineral particles of one kind to aggregate together to form what are known as concretions. They are most frequently formed of carbonate of lime, but sometimes also of iron compounds, and more rarely of silica. By the cementing processes the clays and muds often pass into SHALES or compact MUDSTONES, the sands into SANDSTONES, and the gravel and shingle into CONGLOMERATES or PUDDINGSTONES, while the calcareous muds become more or less solid LIMESTONES. Such changes and others which serve to harden the rocks are assisted by those movements of the earth's crust which uplift the sea floor to form dry land, a subject which will receive fuller treatment in the next chapter.

CHAPTER III

EARTH MOVEMENTS—IGNEOUS AND METAMORPHIC ROCKS

EXTERNAL AND INTERNAL AGENTS.—The foregoing brief review has shown us that at the present day there are various processes in operation which tend to modify the external surface of our globe. Those so far examined act from the *outside*, and their effect is steadily to remove material from the surface of the land and to pile it on the ocean floor.

Inasmuch as a continuance of this operation for a sufficient length of time would reduce all land to the level of the sea, it follows, either that the time during which it has acted has not been long enough, or that there must be some other forces which have an opposite tendency, causing new



DIAGRAMMATIC SECTION OF EARTH'S CRUST FROM N. WALES TO THE MEDITERRANEAN

The height of the section in relation to its length is greatly exaggerated. It is intended to illustrate the general relations of the rock groups along this line.

Probably the greatest thickness of sedimentary rocks is found under the London Basin, where it does not exceed 4 miles.

fact, known that a great part of the earth's surface is composed of rocks which can be proved, both by their constitution and by their organic remains, to have been derived from a pre-existing land area and deposited on an ocean floor. Also, in many places, the bedding- or stratification-planes of these rocks are highly inclined or even overturned; and as from their mode of formation these must at one time have been horizontal, it is evident that they have suffered considerable displacement since that time. The cause or causes which bring about these and analogous results comprised in the term EARTH MOVEMENT have their origin *inside* the crust of the Earth.

CAUSES OF EARTH MOVEMENT.—It is probable that the slow cooling with attendant shrinking of our globe is the primary factor in causing

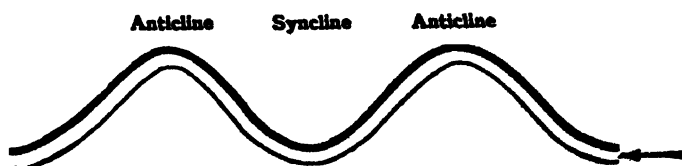


Fig. 14.—Diagram of Symmetrical Folds

displacement of one part of the earth's crust relatively to another. It is a physical law that the higher the temperature of a body the more quickly does it lose heat and contract; therefore the inside of the earth, being at a much higher temperature than the outside, must shrink more rapidly and the external layers tend, therefore, to sag down under their own weight. This sets up enormous strains in these layers, some parts being squeezed together, while others are pulled apart. The squeezing causes gigantic waves or wrinkles to develop in the earth's crust, which are the mountain chains; the stretching in other regions causes enormous fractures, along which parts of the surface are dropped nearer to the centre of the earth, while others remain stationary or are pushed away from it.

MOUNTAIN BUILDING.—Mountain chains may be of every degree of complexity; one of the simplest types is that in which the strata are thrown into one symmetrical wave or succession of such waves. A single wave is known in Geology as a FOLD, and is made up of a CREST or ANTICLINE, and a TROUGH or SYNCLINE (see fig. 14). Such a structure results from the application of lateral pressure to the strata, which forces them to bend in the same way that a sheet of paper laid on a table bends when the ends are pushed towards one another. Continued application of pressure increases the height of the fold in comparison with its width, until

the upper part tends to overhang the base, while extreme pressure may cause that part to be detached; the sides of the fold are then replaced by fractures, or **FAULTS** as they are termed (fig. 15). A mountain chain usually consists of one or more large folds, each made up of a succession of smaller ones, and the crest of each fold may be bounded by faults, which become more numerous and more important towards the centre

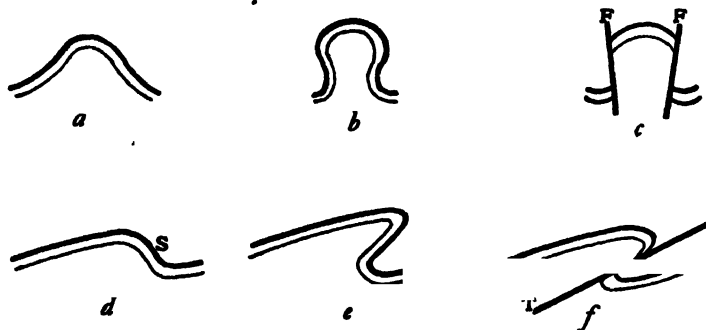


Fig. 15.—*a, b, c*, Diagram illustrating the Passage of a Symmetrical Fold into a Faulted Arch. *d, e*, Diagram illustrating the Passage of an Unsymmetrical Fold, or Monoclinal, into an Overfold and an Overthrust. *s*, septum: *F*, fault: *T*, overthrust (after Marr)

of the chain, where the pressure was most severely felt. It is on such a plan that the Alpine chain is built up, and this structure is therefore known as **ALPINE STRUCTURE**, or sometimes "fan structure" (fig. 16), from the peculiar arrangement of the folds.

Another and more commonly occurring type of fold is unsymmetrical; in this one side, usually known as the **SEPTUM**, is more steeply inclined

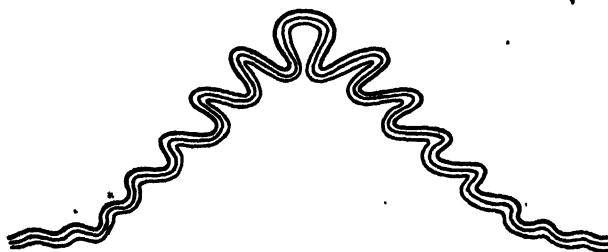


Fig. 16.—Ideal Representation of the Folding of the Alps ("fan structure") (after Marr)

than the other (fig. 15, *d*). More intense pressure increases the inclination of the septum till it overhangs, producing what is known as an **OVERFOLD**, where the older strata rest upon those of later age. Under further stress

the fold is ruptured along the septum, and the crest of one fold is then driven forward along the plane of rupture towards the crest of the fold in front. A fracture of this kind is called an **OVERTHRUST FAULT**, or more simply a **THRUST**. The transition from a simple fold to an overthrust fault is shown in fig. 15, *d, e, f*.

The more complicated structures occurring in mountain chains can usually be resolved into a succession of simple symmetrical or unsym-

EARTH MOVEMENTS

metrical folds combined with overthrusts, which, from their mode of formation, must lie nearly parallel to the direction of the folds. In general it may be said that in a complicated mountain chain the outside folds are more or less symmetrical and free from fractures, while the inner folds are unsymmetrical and accompanied by fractures.

RATE OF ELEVATION.—Although the folds into which the strata are thrown are often exceedingly sharp, it does not follow that the forces which produced them were rapid or sudden in their action. Indeed there is evidence that the elevation of mountain chains has been an exceedingly slow operation, and cases are not unknown where rivers have been able to cut down their channels at a rate sufficient to maintain their courses across a chain in process of formation, which serve to show that the elevation in those cases must have been very gradual. The increase of complexity which may be observed in passing inwards from the margin of a mountain chain towards the centre may be regarded as giving a picture of the succession of events during the formation of the chain, and in this connection the account given by various writers of the movements along the southern margin of the Himalayas is particularly instructive and interesting.

STRUCTURE OF THE HIMALAYAS.—The Himalayan range rises in a succession of hill chains of increasing altitude out of the wide Indo-Gangetic plain which extends across northern India. First come the sub-Himalayas or foothills, rising to about 4000 ft; they are followed by the Lower Himalayas, which ascend to about 12,000 ft.; still farther to the north lies the main range of snowy peaks reaching an altitude of 28,000 ft. and over. North of the main range is the upland plateau of Tibet, of great elevation, and characterized by a dry climate. On this plateau, and therefore beyond the line of snowy peaks, is situated the main watershed of northern India, and the rivers which drain in a southerly direction reach the Indo-Gangetic plain. The materials borne down from the mountains are deposited when the low ground is reached, and consequently the hills are fringed with accumulations of gravel, sand, and mud. These deposits are naturally thicker and coarser near the great rivers, and grade to finer material between them.

The foothills are composed principally of gravels, conglomerates, sandstones or sands, and clays belonging to what is known as the Siwalik series of Upper Tertiary age. They become successively coarser from below upwards, for the Lower Siwaliks are clays and fine sandstones; the Middle Siwaliks are similar, with strings of pebbles, which become more abundant in the upper part, and pass into the coarse gravels of the Upper

Siwaliks. The Lower Himalayas, and main range consist principally of crystalline and sedimentary rocks of great antiquity.

The Upper Siwalik rocks of the foothills are so like in appearance to the gravels and sands spread out on the plain by the rivers at the present day that there can be no doubt that they have been formed in the same way. Further, the distribution of coarse and fine materials agrees so exactly with that of the modern deposits that they must have been carried by the same rivers flowing from the hills on the north and accumulated on a plain similar to the modern plain. The central parts of the Himalayas must therefore have been in existence at that period. But the foothills now rise to about 4000 ft. above the plain, and the rocks, instead of forming horizontal sheets are thrown into sharp folds which are cut into by the

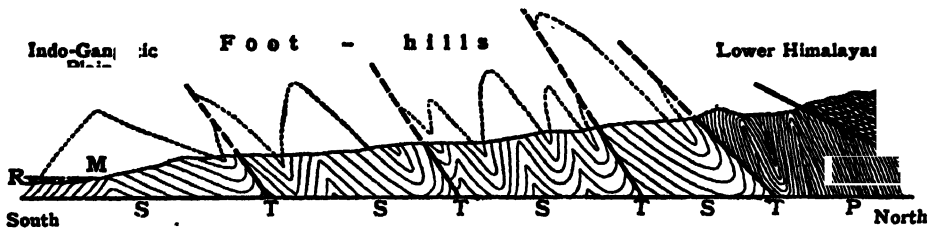


Fig. 17.—Diagram illustrating the growth of the Southern Himalayas. M, margin of plain; S, recent gravels; S, Siwalik rocks; P, old sedimentary rocks; A, crystalline rocks; T, overthrust. [Note gradual increase in the amount of folding and faulting towards the centre of the chain.]

modern rivers coming down from the interior. It is evident, therefore, that what was once a part of the plain has been disturbed, elevated, and exposed to considerable denudation; that, in fact, the southern boundary of the Himalayas in the Siwalik period was many miles to the north of its present position, and has crept steadily southwards towards the plain since that time. The modern gravels rest on the tilted-up and eroded edges of the Siwalik rocks, for the latter, where they come in contact with the deposits along the northern margin of the present plain, are thrown into an anticlinal fold in which the south side is steeper than the north, and may be vertical or even inverted; in certain parts an overthrust fault is *believed to exist along this line*.

Passing now to the inner or northern margin of the foothills, where they pass into the Lower Himalayas, it is found that the structures are more complicated; the boundary between the Siwalik series and the older sedimentary rocks, probably of Palæozoic age, is found to be a great reversed fault accompanied by one or more overturned anticlinal folds. From the distribution of the Lower Siwaliks, and from analogy with the conditions at the margin of the modern chain, it is probable that this fault coincides

EARTH MOVEMENTS

approximately with the southern limit of the range during the formation of those rocks, and therefore marks a still earlier position. The Siwaliks themselves are traversed by several reversed faults of great magnitude, and each appears to mark successive positions of the southern margin as it advanced towards the plain. The appended diagrammatic section (fig. 17) across the outer zones shows the gradual increase in the intensity of the movements from the margin to the interior. From the above account it follows that the elevation of the Himalayas was by no means a sudden movement, but was more of the nature of a gradual growth both in lateral extent and in altitude, which lasted through a great part of the Tertiary period. The greater complexity of the interior is therefore due to the longer duration of the movement there; for the same reason the height of the range increases steadily from the margin inwards.

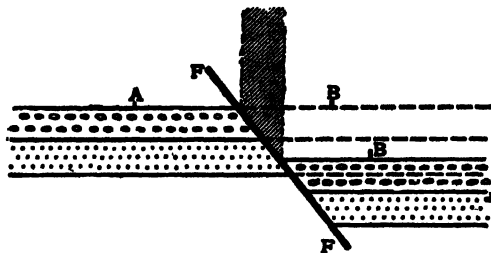


Fig. 18.—Diagram of a Normal Fault. The amount of stretching of the strata shown by the shaded area

FAULTING.—The kind of structures we have been considering are due to lateral compression of the rocks, but another kind results where the strata are subjected to tension tending to pull them apart. The stretching is accomplished by a tearing of the strata, and subsequent slipping along the **FAULTS** or tears, the type most commonly occurring being known as **NORMAL FAULT** (fig.

18). It is easy to see that by such faulting any two points A and B on a given stratum are farther removed after the operation than before. The

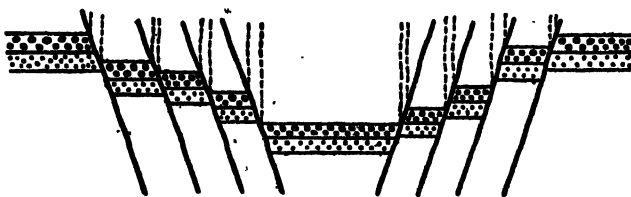


Fig. 19.—Step-Faulting. The amount of stretching is represented by the spaces between the broken lines

amount of stretching is indicated by the shaded space. Such structures lead to the formation of troughs in the strata, which may be the result of a single normal fault on each side, or more usually a succession of such faults, known as **STEP FAULTS** (fig. 19). The extension is shown by the spaces between the broken lines. Normal faults frequently accompany the elevation of a mountain chain, but in distinction to the overthrusts they trend at right angles to the direction of the chain, or parallel to the pressure which uplifted it. This indicates that in addition to lateral compression acting across the chain there must be a tension acting along it.

SUBSIDENCE.—Whereas compression and distortion of the strata are held responsible for much of the emergence of land from below the sea, it is to the other type of movement that widespread subsidence of blocks of the earth's crust is attributed. It has been observed that after the forces of upheaval have almost or quite expended themselves in a region, there is a tendency for parts of that region to subside along normal faults. It is as if those forces had overreached themselves, necessitating a falling back of some of the uplifted portions in order to restore the equilibrium. Subsidence by normal faulting is not, however, confined to regions which have suffered compression, but may occur in quite other parts of the earth's surface. It is claimed by Professor Suess that the deeper parts of some of the great oceans, notably the Atlantic and Indian Oceans, have originated almost exclusively by the collapse of enormous blocks of an ocean floor, or of a land area which formerly occupied their sites, and, further, he supposes such collapse to be of comparatively recent date. References to those movements will frequently be made in the sequel.

VOLCANOES AND EARTHQUAKES.—The story of earth movements would not be complete without some reference to those phenomena of volcanic activity and earthquake shocks which accompany them. It was at one time believed that the upheaval of portions of the earth's crust and the attendant folding and faulting were mere surface indications of deep-seated volcanic forces, while powerful earthquake shocks were held responsible for widespread cataclysmic changes, which altered profoundly the aspect of the earth's surface; in other words, volcanic activity and earthquakes were the causes and earth movements were the effects. The balance of modern opinion tends to reverse that view; it is held that the surface eruptions of volcanic material and the injection of molten masses into the rocks at a depth are only local effects of those powerful forces, which produce widespread elevation or depression of parts of the earth's crust, while it is known that violent earthquake shocks may result from quite unimportant displacements; indeed, those displacements are often so small that they produce no measurable change of level in the region affected by them.

MAGMAS—IGNEOUS ROCKS.—Vulcanicity may be considered under the heads of external and internal processes, which stand, however, in intimate relation to one another. Deep down below the surface of the earth there exist in many regions great reservoirs of molten rock; whether they form part of a universal molten interior, or of a liquid shell between a solid crust and a solid core, or whether they have arisen

as well as oxides and sulphides of certain metals, especially iron. According to the relative proportions of silica to the metals, magmas are roughly divided into ACID and BASIC, the former being rich in silica and poor in the metals, while in the latter the proportions are reversed; those of a mean composition, in which the proportions are more evenly balanced, are said to be INTERMEDIATE, while certain magmas exceptionally poor in silica are styled ULTRABASIC. The rocks into which such magmas solidify on cooling are classified in a similar way. It may be remarked that the melting down of sedimentary rocks would, in general, give a magma differing in chemical composition somewhat markedly from those existing at, or derived from, the deep-seated portions of the earth, although the source of all sediments can be ultimately referred to rocks which had their origin at great depths. The reason is, that the process of weathering is almost always attended with the removal in solution of certain constituents, which, becoming distributed throughout a large body of water, enter into the composition of sediments of quite a different region from that where the insoluble constituents are deposited. In other words, the denudation of rocks by weathering results in a scattering of their constituents which never reunite in the same rock mass. Of course, by the melting up of a judicious selection of various types of sedimentary rocks, in certain proportions, it is probable that any given magma could be simulated, but such a selection cannot well occur in nature. It follows, therefore, that most magmas are of deep-seated origin, and that no part of their bulk has been sufficiently near the surface of the earth to have suffered denudation.

ORIGIN OF MAGMAS.—Adopting the more probable suggestion that they result from the melting of rocks previously solid, it is necessary to enquire why liquefaction should occur. Increase of temperature by chemical combinations, by intense crushing, by the accumulation of thick masses of sediment at the surface and consequent bottling up of the internal heat of the earth, or by a change in composition of the magma have all been appealed to as sufficient causes to bring about liquefaction. It is likely that each of them acts in the right direction,

BEHAVIOUR OF MAGMAS—METAMORPHISM.—When liquefaction has set in, the magma obeys approximately the laws governing the behaviour of fluids, and flows towards the regions where the pressure is lowest, until equilibrium is restored. The magma therefore forces its way into the overlying strata, insinuating itself wherever the opposing pressure is not too great. If planes or lines of weakness exist, they offer a ready passage to the molten mass. This is probably another reason why volcanic activity should so constantly accompany earth movements, for those disturbances, as we have already seen, result in the production of enormous fractures, which probably penetrate to great depths. Also, in the earlier stages, the stresses in a region are irregularly distributed, else no movement could occur, but towards the end they become adjusted or relieved by the folding, faulting, and crushing of the strata. Unequal stresses are obviously favourable to the intrusion or injection of the molten material. Its ultimate resting place is usually among rocks which are at a much lower temperature than itself, and in many cases it reaches the surface and flows out thereon; but the consideration of such is withheld for the present. The rocks through which it passes, and those among which it comes to rest, are profoundly altered by reason of the high temperature of the molten mass. The extent of the alteration depends on the depth, which determines the time taken in cooling; the composition of the intruded magma, which determines its melting-point; the nature of the affected rocks; and on the distance of the latter from the source of heat. The changes produced in the surrounding rocks are comprised in the term **THERMAL METAMORPHISM**, while the whole region over which they are manifested is known as the **METAMORPHIC AUREOLE**. The chemical elements entering into the composition of the minerals in the rock recombine to form different minerals, and in extreme cases the original rock is entirely changed in aspect and in mineral composition. At greater distances, where the temperature is lower, the changes are less marked, and only make themselves felt in the more easily altered minerals; but near the contact with the magma, portions of the containing walls are often profoundly altered or even melted down.

distinguishable owing to their crowding together.

COOLING OF MAGMA.—The case is somewhat different if the intrusion nearly reaches the surface, where the cover of rocks is small; cooling then takes place quickly, and the metamorphism is consequently much less pronounced. The appearance of the cooled rock is also different, for after crystallization has proceeded some time, and crystals of considerable size are floating about in the magma, the remainder tends to solidify suddenly into a mass of minute crystals, or more rarely into a glass. Any large intrusive mass sends off innumerable tongues and veins of molten material into the surrounding rocks; some of these often penetrate to great distances from the parent magma, especially along planes of weakness. Their consolidation takes place in the manner just described. Those that spread out in directions more or less parallel to the stratification of the rocks are called **SILLS**, while those that cut across them at an angle are known as **DYKES**.

LAVA.—It is probable that the material which wells out in volcanoes is fed from some large underground reservoir, and has been enabled to reach the surface by following important planes of weakness; for the tendency of volcanoes to be arranged in lines along prominent faults is well known. The molten material pouring out from the opening flows over the surface as sheets of lava until it is prevented from doing so by cooling and solidification. The distance to which individual flows reach depends on their chemical composition—basic lavas, being more fluid, reach to great distances; while acid lavas, being viscid, the flows pile themselves around the aperture or vent, and rapidly decrease in thickness away from it. There is thus a tendency to build up the cone-shaped hills characteristic of recent volcanoes.

VOLCANIC ASHES.—In most cases, however, lava flows play but a subordinate part in building up the cones; in the intervals of lava eruption great quantities of ashes, cinders, and fragments of consolidated lavas are hurled out of the crater and piled on the slopes around. Such fragmentary materials are probably produced by the forcible escape of steam imprisoned in the hot lava; the "smoke and flame" of popular descriptions of volcanic eruptions are only immense clouds of steam, black with innumerable solid particles, which reflect the lurid glow of the molten mass in the

neck of the volcano. Some cones are built up entirely of ashes and cinders, without any lava flows, while others are formed of alternate layers of lava and ashes.

CHARACTERISTICS OF LAVA FLOWS.—The appearance of the surface of a lava flow varies greatly in different cases. Some are blown up into a vesicular or cellular mass, like baked bread, known as pumice, by the escape of steam on cooling; others have a coiled or ropy surface, produced by the rolling over and over of a half-consolidated pasty mass while others are strewn over with sharp, angular fragments, splintered from the consolidated upper layers by the pressure of the movement in the still-fluid interior. The consolidated rock or lava usually shows large well-formed crystals of various minerals set in a matrix of minute crystals usually mixed with a certain amount of glass; in some the glass predominates, and in others the large crystals may be absent, the rock being then an exceedingly fine-grained compact rock or a glass.

INTERMITTENT NATURE OF VOLCANIC ACTION.—Most volcanoes are intermittent in action, violent periods alternating with long periods of quiescence or total inactivity. During the eruptions, part of the crater is often blown away, and the next accumulations are built up on its ruins. The famous eruption of Krakatoa, in 1883, blew away the greater part of the crater in one tremendous explosion. Small "parasitic" cones often cumber the slopes of the volcano, and are connected with the main orifice or neck by fissures. An old volcano which has been dissected by the weather often shows a great number of ribs of lava or dykes which have penetrated along such fissures in all directions.

The height of the cone in relation to its width depends largely on the nature of the materials; basic lavas form low cones of great diameter, while acid lavas form narrow cones of considerable height; those made up mainly of lavas have a gentle convex outline, but where ashes and cinders take a prominent place the cone consists of two concave portions meeting at the apex.

Another type of eruption is known as **FISSURE ERUPTION**, where the lava wells out, not from a single vent or orifice, but along the whole length of a fissure. In such eruptions the lavas are usually of basic types, and from their fluidity flow to great distances; the materials from many fissures uniting together give rise to a vast sheet of lava, which enters into all the irregularities of the surface just like a body of water. It is probable that such eruptions are due to the sinking of large blocks of the earth's crust into a huge reservoir underneath, the molten material being displaced according to well-known hydrostatic laws; it is probable also that such

a process plays no small part in ordinary eruptions, for it has been frequently observed that sinking of a region generally accompanies volcanic activity, while earthquake shocks are almost always felt before a volcanic eruption, pointing to a common cause.

Hot springs are also a result of volcanic activity. The waters of these springs become covered by a thick coating of a substance which, when dried, forms and picturesque terraces with pools of water are frequently formed in this manner. It is supposed that the deposition of silica is assisted by certain algae which are able to live in the hot water.

The distribution of volcanic activity at the present day will be indicated in a later chapter, while the vulcanicity of past periods of the earth will be referred to in connection with those periods.

EARTHQUAKES.—It has been remarked that shocks generally precede and accompany volcanic eruptions, and from the close connection of seismic areas with those of vulcanicity it is obvious that the two classes of phenomena are intimately related to one another.

But as earthquakes are not strictly confined to volcanic areas, there must be some other determining cause, and it has been suggested that they arise from sudden slipping of parts of the earth's crust along fault-lines. If this is so, then vulcanicity and seismic activity can probably be attributed to a common cause—earth movement. It is only in a few cases, however, that the faulting which may be supposed to have originated the shock has produced any visible effect at the surface; in others, apart from the damage from the actual vibration, the condition of the surface remained unchanged.

Some comparatively recent earthquakes, however, have given rise to gaping fissures of great length, and faulting has occurred in consequence; but the amount of displacement was a matter of a few inches as a rule. Warping or buckling of certain regions has accompanied severe earthquakes, whereby the courses of streams were changed, and lakes were formed in the hollows. Very destructive effects are often due to landslips caused by shocks, while along coast-lines the tremendous waves which follow a great earthquake have occasionally worked considerable havoc.

STUDY OF EARTHQUAKES.—Recent studies of earthquakes have thrown considerable light on the internal constitution of the earth. By means of delicate instruments shocks can now be registered at a distance of thousands of miles from the source. In general, three disturbances reach the recording station; the last to arrive travels along the crust, the other two through the earth nearly in the direction of the chord joining the two

points. The former gives no information regarding the interior, so may be neglected for the present purpose. Of the remaining disturbances the one that arrives first is supposed to be transmitted by the alternate condensation and expansion of the parts of the medium which transmits them, the other by a twisting or distorsion of those parts. If this view is correct, then the medium must be solid, or at least must behave as a solid, since a fluid cannot transmit twisting stresses. Now, these two kinds of waves, as they may be called, travel with different velocities, and hence give some clue to the elastic properties of the medium through which they pass. The difference in velocity increases slightly with the greatest depth of the chord from the surface, until a distance is reached where the depth of the chord is about three-fifths of the radius. A somewhat abrupt change then takes place, especially in the second waves, indicating that the matter composing the inner two-fifths of the radius of the globe has different elastic properties from the rest of the material. It is not known as yet to what this difference is due; but when a greater number and more accurate observations of distant shocks have been compared, it is probable that much new information will be obtained regarding the nature of the interior of the earth. A comparison of the velocities of propagation of the first and second waves, which travel through the earth, with that of the third wave, which travels near the surface, indicates that the thickness of the crust is probably not more than about 20 miles.

CHAPTER IV

CYCLE OF DENUDATION

We have now traced the processes of denudation of the land areas and of the deposition of the derived materials on some part of the ocean floor, and we have seen how after a lapse of time of greater or less duration these may be once more uplifted to form land, which in its turn becomes worn away. Geology shows that changes of this kind have succeeded one another many times during that period of the past history of the earth of which the record is preserved in the rocks. It remains to consider more closely the series of events which succeed one another (in a temperate region) between the birth of a new land area as the result of earth movements and its final destruction by denudation or, in other words, a complete CYCLE OF DENUDATION.

SYMMETRICAL UPLIFT.—A clearer idea of the sequence of events will be gained by considering a simple example which embodies the principles underlying more complicated cases. Let us imagine a portion of the sea floor, on which a considerable thickness of sediment has accumulated, to be uplifted above the sea level in the form of a simple arch or anticlinal fold of symmetrical type; the two shore lines will then be parallel to the crest of the arch. From the nature of the symmetry the changes on one side will be like those on the other, and one may therefore regard the new land area as consisting of two slopes inclined in opposite directions towards the shore. Rainwater falling on the surface of the land accumulates and carries it down the slopes. A part of the rainfall soaks into the ground, and after a time accumulates sufficiently to saturate the rocks with water; the excess tends to break out on the slopes in the form of springs, and thence takes the shortest course down to the shore. For the sake of maintaining the symmetry, we suppose the springs to be of equal volume and to be distributed at the corners of equilateral triangles, as shown in the diagram (fig. 20). When once started, the springs tend to maintain their positions and a more or less constant flow, and the channels carved out by them at their initiation become the main stems of the drainage system which ultimately develops on the slopes.

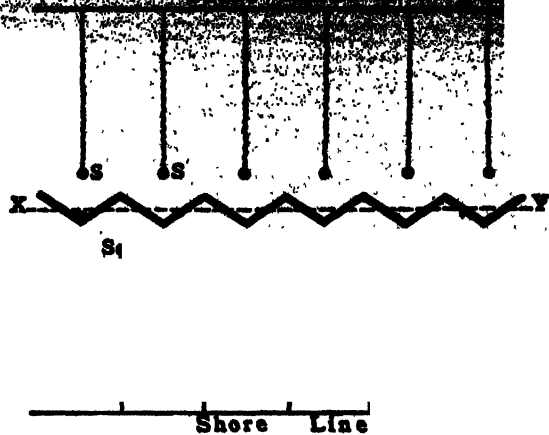


Fig. 20.—Plan of a Symmetrical Drainage System

s, spring; xy, crest of arch on which drainage system was initiated. The mature primary divide is shown by the thick zigzag line.

BEHAVIOUR OF A SINGLE STREAM.—In dealing with the influence of running water in modelling the surface of the land, it will be convenient to consider in the first place the behaviour of a single stream, and to pass on from that to the assemblage of streams which constitutes the drainage system. We have supposed a stream to be started on a sloping surface, and to flow down to the sea along the shortest course. Under these conditions the volume of the stream remains unchanged along its whole length, but the velocity increases with the distance from its source in the same way as that of a body rolling down an inclined plane. As we have already seen, the power of a stream depends on its velocity when everything else remains the same; therefore the channel will be deepened by corrasion more rapidly

in the lower part of the slope, say at B, than at A, where the stream is practically at rest (fig. 21). But as the material thus removed from the channel must be carried away, more and more of the power of the stream is required for this purpose as the amount of the material increases; therefore at some point, such as C, most of the power is used up in transportation, and the cutting-down action or corrasion is reduced, though not necessarily stopped altogether. At a still lower point, D, the whole

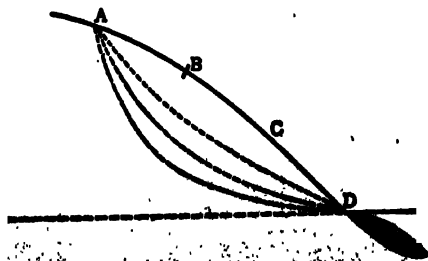


Fig. 21.—Diagram illustrating the Development of the Denudation Curve of Running Water

power of the stream may be used up in transportation, and no cutting down can then take place. Hence at some point down the slope the corrasion is more active than elsewhere, so that after a certain time the profile of the stream, which was originally a straight line or a curve convex upwards, has become a concave curve. The stream channel retains a profile of this nature throughout its life history; it is steepest near the source, and flattens towards the mouth. It is a characteristic feature of denudation by running water.

When the stream reaches the sea the velocity is checked and the coarser sediment is dropped near the mouth, while the finer is carried farther out to the sea. The deposition at the mouth checks the velocity higher up the channel, thus reducing the power of the stream in that



Fig. 22.—The Development of a V-shaped Valley under the Action of Weathering

direction. This in turn stops corrasion, and more and more sediment is dropped in the lower part of the valley.

The stream may therefore be divided into three parts: (1) near its source, where corrasion is small on account of the small velocity; (2) median portion, where it is rapid; and (3) a lower portion, near the mouth where, on account of the retardation of the velocity, corrasion is absent and even deposition may take place.

So far the influence of weathering has been neglected, and the stream has been supposed to cut a groove with vertical walls in the hillside. Such vertical walls cannot remain long under ordinary conditions of weathering. Material is loosened and dislodged, and, falling into the stream, is removed by the water, so that in time the sides of the channel

recede, as shown by successive dotted lines in the diagram (fig. 22), and the original channel widens into a V-shaped valley. When this happens the original stream can no longer exist alone; miniature streams and runnels start with every shower of rain, while new springs arise on the lateral slopes. These give rise to valleys by a repetition of the processes sketched above; they may be termed secondary valleys to distinguish them from the main or primary valley.

In time these secondary streams come to have tributaries of their own, which flow in tertiary valleys, and so on, the process being repeated until the ground is carved into innumerable branching channels carrying streams of all sizes, from that of the main stream down to that of the tiniest runnel. The head of the valley, like the sides,

is ultimately cut into a half-funnel shape

sloping towards the spring, which occupies

the bottom of the funnel. It is known as a **CIRQUE**, and may be observed at the head of most valleys.

DRAINAGE SYSTEM.—Let us pass on next to consider the assemblage of streams, flowing side by side down the slopes, which forms the drainage system of the new land area. Each stream has carved out its channel to a concave profile, and each has given rise to secondary and tertiary tributaries, while the cirques at the head of each primary valley have cut back towards the line separating the drainage of the primary streams on opposite sides of the slopes.

This line is called the **PRIMARY**

or **MAIN DIVIDE**. As all the

streams on the slope have the

same volume, the divides are situated midway between them; but in a maturer or fully developed system they are not, as a rule, straight lines, as the following explanation will show. A point A (fig. 23) on the line joining the heads of opposite streams is the point where their cirques ultimately meet; it is therefore under the denuding influence of both streams, and is reduced in height at a greater rate than a point B, which is at the farthest distance from the streams. The divide between two primary streams therefore runs at right angles to the line joining their sources, and, moreover, is a curve concave upwards; hence the whole primary divide follows a zigzag course, and if viewed in profile has the appearance in fig. 24.

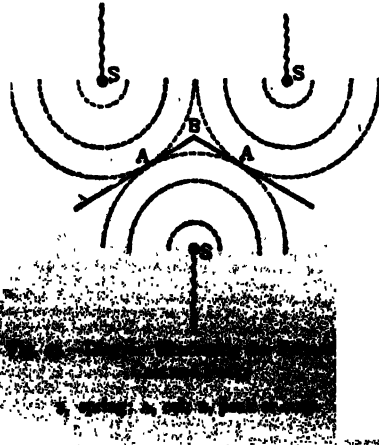


Fig. 24.—Profile of a Mature Primary Divide

The points such as A are called COLS or PASSES, while the points B are PEAKS or CUSPS.

The rate of corrasion by the secondary streams depends on the fall from source to mouth; therefore where the main valley is most actively excavated the fall of the secondary streams is greatest, and their channels are deepened most rapidly. The secondary divides are also zigzag lines and are developed in a similar manner to the main divide. But inasmuch as the lowering of the divide proceeds most quickly opposite the most active streams, it follows that the profile of the secondary divide is closely related to that of the main valleys on either side, and indeed if a line is drawn through all the secondary cusps, or all the secondary cols, the profile thus obtained exactly resembles the characteristic curve of the primary valleys. In general it may be said that the result of denudation

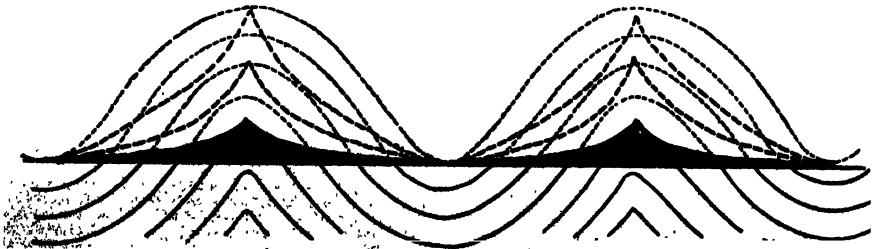


Fig. 25.—The Formation of a Peneplain in Folded Strata

by running water is to carve the surface of the land into valleys and hills, all of which show the concave profile indicated above, which may be called THE DENUDATION CURVE OF RUNNING WATER, and as this agent is the most active and most widely distributed, it follows that this is the outline most frequently met with. Most of the great mountain chains exhibit a profusion of these typical curves, and, indeed, largely owe to them their grace and beauty.

INFLUENCE OF FOLDED STRATA.—We have already seen that the most general result of earth movement is to throw the strata into a succession of crests or ridges, which are convex in outline, separated by troughs or valleys. In the subsequent denudation of such a region each ridge gives rise to two sets of streams flowing down opposite slopes into the bounding valleys. The crest of each ridge becomes the main divide, and the secondary divides are arranged nearly at right angles to it. All the divides at first are straight, but, as described above, they ultimately become zigzag. As denudation progresses, the convex ridges resulting from earth movement are replaced by the characteristic concave curves somewhat as shown in the diagram (fig. 25). There is thus an essential

difference between the surface outline produced by those agencies acting from within the earth (which are comprised in the term earth movement) and those acting from without (denudation). Where the former predominate convex outlines are the rule, but where the latter predominate they become the exception, being replaced by concave curves. This difference will be referred to again, when the features of the land surfaces are compared with those of the sea floor.

PENEPLAINS.—If the conditions remain uniform throughout the period of denudation the positions of the streams and divides remain unchanged, but their heights are gradually reduced, as shown by the successive broken lines in the diagram (fig. 25). The final stage, shown by the firm line, approximates to a plain, which has been termed by American geologists a **PENEPLAIN** (almost a plain). The divides and valleys are but faintly marked, and the streams, having done their work, can reduce the land area no lower by ordinary denudation. The form of the original surface can, however, be inferred not only from the positions of the divides and valleys, but from the inclination of the strata; and, in fact, by studying carefully the disposition of the rocks it is often possible ideally to restore the form of the uplifted land surface before the agents of denudation began their destruction.

COMPLEX RIVER SYSTEMS.—It is found, however, that in nature the conditions are not always as simple as in the cases described above. The main streams are not of equal volume, and are not always so regularly arranged. The folds into which the strata are thrown are not as a rule symmetrical, and, in fact, unsymmetrical folds are of more common occurrence. Again, the rocks which the streams encounter in different parts of their course are not of equal hardness; more usually they are arranged in alternating hard and soft layers. Some rocks, such as limestone, are soluble in water to a considerable extent, and these may alternate with others which are insoluble. Any one of these causes leads to modifications in the result explained above.

STRUGGLE FOR EXISTENCE BETWEEN STREAMS.—The most common case of departure from simplicity is where one of several streams (A in fig. 26) flowing down a slope is more powerful than its neighbours from possessing a greater volume. A struggle for existence then sets in, where the victory goes to the strongest at the expense of its weaker competitors. As the rate of down-cutting depends on the volume, other things being equal, the stronger stream is able to outpace its neighbours. This gives a greater fall to its tributaries, and they extend their valleys unduly towards those of the less-powerful stream (B). The divides are there-

fore shifted in that direction, and the stream which already possessed the greater volume receives more than its former share of the rain which fall on the area, and is therefore further strengthened. Its tributaries become still more active, and the shifting of the divide goes on a further step. A time comes when one of the powerful secondary streams (D) taps the tributary (E) of the sister stream (B), and ultimately the main stream itself, diverting the water down its own valley. This piracy may extend to other tributaries in turn, and each increase of volume only serves to make the already victorious stream and weaken its impoverished neighbour, in case one or more of the latter may lose all their higher

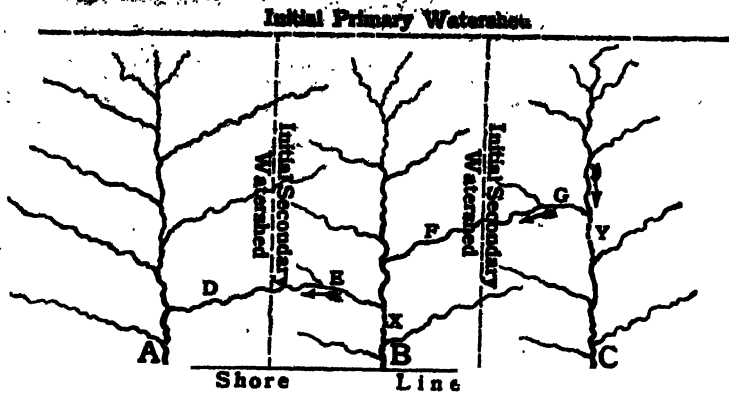


Fig. 26.—The Capture and Beheading of Streams ("stream-piracy"). The dotted lines at x and y show the original course of the streams B and C

tributaries by diversion into the adjoining valley, when they are said to be **BEHEADED**, as B at X and C at Y.

Similar results may be produced if the position of the divide was originally unsymmetrical from the drainage having originated on an unsymmetrical fold. Another frequent cause of diversion of a drainage system is the unequal hardness of the rocks in different parts of the course of the stream. Let us suppose a number of parallel streams to be flowing down a slope across alternate belts of hard and soft rock. In the soft beds the tributaries push back their headwaters more rapidly than in the hard, so that the streams along these belts are in a position to interfere with one another, and if one possessed originally a slight advantage in strength it succeeds in robbing its neighbours, and ultimately beheading or diverting the main stream. At a later stage other streams may be captured, so that finally several of those which originally flowed side by side across the strata may be forced to flow along one of those belts of soft rock.

EVOLUTION OF THE RIVER SYSTEM EAST OF THE PENNINE

RANGE.—An instructive example is afforded by the rivers which drain the eastern slope of the Pennine chain of the north of England. Originally a number of parallel streams started in an easterly direction across the outcrops of the Mesozoic group of strata (see p. 128). Two of the members of this group, the Trias and the lower part of the Lias, consist



Fig. 27.—Sketch Map of the Drainage System on the east of the Pennine Chain

of soft clay, marls, and incoherent sandstones, which are bounded on each side by harder rocks—on the west the Permian sandstones and limestones, and on the east the hard strata of the upper part of the Lias and Oolites (see fig. 27). One of the present streams, the Aire, finds its direct continuation in the Humber, and we may regard the Aire-Humber as one of the original streams. The Ouse, which runs from north to south, is a tributary of the Humber. It lies on the belt of soft Triassic rocks, and has extended its headwaters far to the north. In so doing

it has intercepted several of the other easterly-flowing streams, of which the Swale, the Ure, the Nidd, and the Wharfe represent the upper remnants. Another tributary of the Humber on the south is the Trent, which likewise has extended its headwaters in an extraordinary manner, tapping a number of streams, such as the Derwent and others, which must originally have reached the sea in an easterly or south-easterly direction, and even interfering with some of the tributaries of the Severn and the Warwickshire Avon.

EVOLUTION OF THE THAMES SYSTEM.—It has been maintained that the modern Thames is only the beheaded remnant of a much longer river which flowed from the west. Its original headwaters are perhaps represented by those of the Severn. The diversion in this case is supposed to have been effected by the lower Severn and its direct continuation the Warwickshire Avon working backwards along the soft beds of Trias and Lias until the old Thames valley was reached.

CONSEQUENT DRAINAGE SYSTEMS.—In all the examples hitherto considered the drainage has been supposed to originate on a slope which was itself the direct result of earth movement, and are styled by American geologists **CONSEQUENT** drainage systems, *i.e.* they are directly consequent on an uplift of the strata and bear an intimate relation to it. The troughs or synclinals are occupied by watercourses, and the crests or anticlinals are the primary divides.

RIVERS OF THE WEALD.—One of the most striking English examples is the drainage of the Weald, which was started on an arch of Lower Tertiary strata elevated during the period of the Alpine earth movements. The crest of the arch ran from east to west, and the streams on the northern slope flowed into the trough forming the London Basin, where is now the Thames. The southern streams probably drained into a parallel trough forming the eastward continuation of the Hampshire Basin; but this part is now submerged under the channel (fig. 28).

ANTECEDENT DRAINAGE SYSTEMS.—Another type of drainage system is said to be **ANTECEDENT**, *i.e.* the streams were in existence before the earth movement, and maintained their courses open throughout it. It is considered that the Indus and Brahmaputra, which cross the Himalayas at opposite ends, were in existence before the beginning of much of the Himalayan uplift, and that they succeeded in keeping their channels open during the elevation of the chain. When one considers how slow is the cutting-down action of a stream, whatever its size, one will gain some idea of the enormous length of time involved in the elevation of a great mountain range like the Himalayas.

CYCLE OF DENUDATION.—When a tract of land which has been elevated by earth movements has been reduced to the state of a peneplain, it is said to have gone through a **CYCLE OF DENUDATION**. A peneplain cannot, however, be worn down to or below sea-level by this means, so that without other agencies it can never be covered again by marine deposits. It is probable that with the occurrence of subsequent movements and other agencies, the land may be raised above level of the sea by the action of waves and other agencies of solution, but it is doubtful whether any tract of land has remained immovable for a sufficient length of time to allow a cycle.

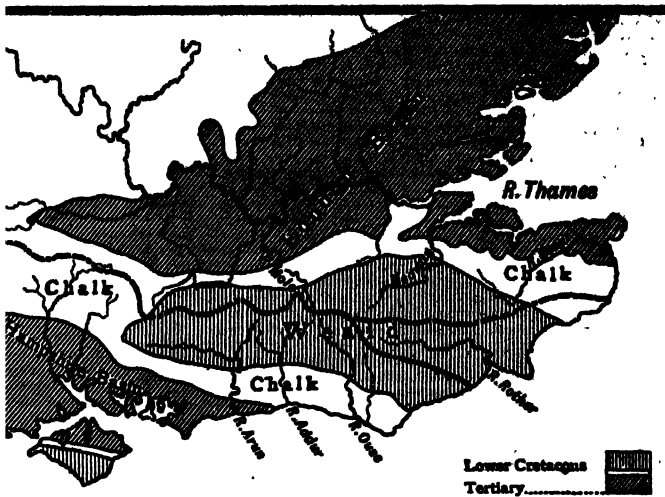


Fig. 28.—Sketch Map of the Drainage System of the South-east of England

course to the end. As a rule, in the past history of the earth renewed movement occurred before it was completed, and the approximately planed surface was either uplifted or depressed. These two possibilities may be considered in turn.

UPLIFTED PENEPLAIN.—If the whole tract is raised the streams which were flowing sluggishly down to the sea are given new power on account of the increased fall between source and mouth, and they at once begin to cut down or corrade their channels. This action begins at the mouth, and gradually spreads inland, so that after a time deep valleys border the sea margin, whereas farther inland the old shallow valleys remain unchanged. If the uplift takes place without tilting the tract the streams retain their positions and all their windings, and merely entrench themselves along their former channels. In this way are often produced intricately winding gorges sunk deep in an elevated

plain. The Wear at Durham is supposed to illustrate this condition of things. If now the elevation of the already existing plain is reduced to another peneplain at a low level, or until a new set of movements disturbs the process.

SUBMERGED PENEPLAIN—UNCONFORMITIES.—If the plain is depressed below sea-level it becomes covered by a fresh set of deposits arranged in horizontal sheets. As we have already seen, the rocks forming the plain had been tilted to various angles before the denudation began, so that the new deposits rest on the inclined and planed-off edges of the older set, producing the appearance known in Geology as an UNCONFORMITY (A B, fig. 29); it shows that the area where it is observed has passed through the following succession of events: (1) Deposition of the



Fig. 29.—An Unconformity

older set of strata; (2) uplift of the area, accompanied by folding of the rocks; (3) denudation of the uplifted strata to a plane surface; (4) depression of the

denuded surface below the sea; and (5) deposition of the newer or overlying set of rocks. It is obvious that a second uplift of the area, followed by denudation, must take place before the unconformity can be brought under observation.

SUPERPOSED DRAINAGE SYSTEMS.—If after a period of quiet sedimentation the sea floor suffers another elevation above the level of the sea, a drainage system is started on the surface of the newer deposits which bears a direct relation to that uplift. Denudation then begins to remove the newer beds, and in time the streams cut down to the underlying older rocks at certain places. If the elevation has been of sufficient amount they do not stop there, but continue to deepen their channels in the latter strata. At a much later stage the whole of the newer cover may be denuded away, and the stream channels are then carved entirely in the older rocks. As the drainage originated on a cover of rocks which was folded in a certain way, it was quite independent of the direction and amount of folding in the strata underlying the cover, and, without knowing the circumstances under which the drainage was originated, one might well be puzzled at the absence of any relation between the streams and the structures in the rocks over which they flow. It is claimed that the drainage system of the English Lake District offers an example of this (fig. 30). The drainage probably started on a dome of carboniferous or newer rocks.

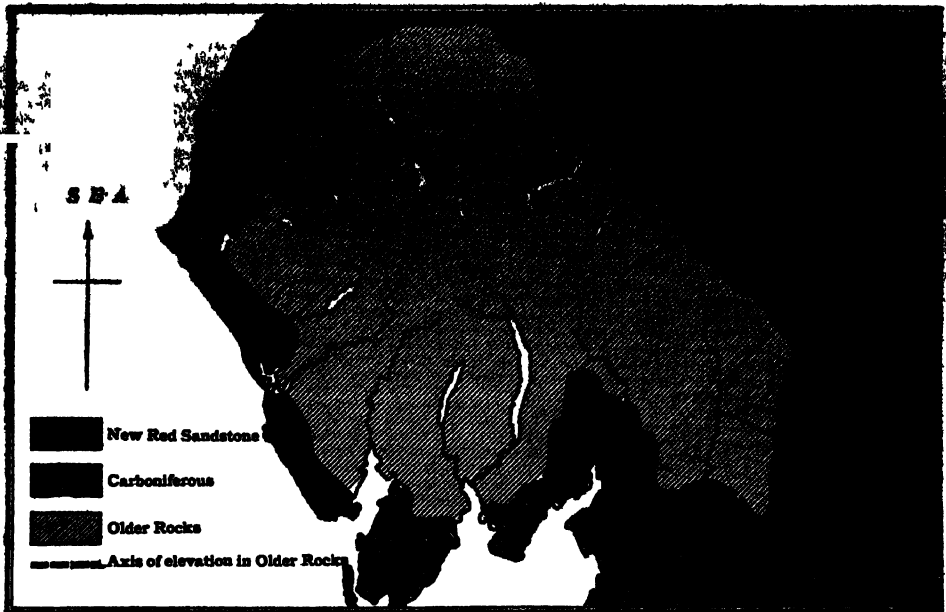


Fig. 30.—Sketch Map of the Drainage of the English Lake District (after Marr)

CHAPTER V

EARTH HISTORY—ORIGIN OF THE GLOBE

EXPLANATION OF PAST BY PRESENT.—The reader has now been made acquainted with the more important forces which are capable of modifying the external features of our globe, and with the results which follow from their operation. In Modern Geology the assumption is made that these forces and their results were—in the main—of the same *kind* in past times as those which are in operation at the present day—an hypothesis which is warranted by many lines of evidence, some of which will appear at a later stage. It does not follow, however, that those forces were not more intense in their action, or, in other words, achieved the same results in a shorter time.

CATASTROPHIST VIEWS.—In the early days of Geology it was the prevalent notion that the earth had been affected at intervals in its career by violent convulsions, cataclysms, or catastrophes, which altered suddenly the whole aspect of its surface; the old order of things was destroyed and a new order set up, which prevailed until it was upset in its turn by a renewed cataclysm. With the increase of knowledge and the emancipation

of thought, following on the introduction of more scientific methods of investigation, it was gradually recognized that these views were not supported by evidence, and, moreover, were unnecessary, for it was shown that the observed facts could be explained in a rational manner without having recourse to such violent means.

UNIFORMITARIAN VIEWS.—The reaction from the old catastrophic views gradually drove geologists to the other extreme, and the *uniformitarian* teachings of Hutton and his exponent Playfair were generally accepted and followed. In his *Theory of the Earth* Hutton describes the formation of hills and valleys by the ordinary mechanical agencies; he saw the resemblance of the rocks of the earth's crust to deposits which are forming at the present day, and argued that they had been formed in the same way, and had attained their actual position by subsequent uplift. He then enunciates the view that the forces of past times have been the same as those of the present, and have acted with the same intensity. He further remarks: "In the economy of the world I can find no traces of a beginning, no prospect of an end", for he imagined the old rocks to have been derived from pre-existing rocks, themselves perhaps the ruins of still earlier rocks, and that the same process might be repeated indefinitely throughout the future ages.

EVOLUTIONARY VIEWS.—Within the last few decades the principles of evolution have pervaded Geology in common with other departments of science, so that there is now a tendency to abandon the strict uniformitarianism of Hutton, and to take up an evolutionary standpoint. On this view the forces of change have not necessarily been of invariable intensity from the beginning of the earth's history, neither have they attained the excessive violence implied in the catastrophic notions; they are assumed to have varied in intensity following the variations in the internal heat of the earth and the radiation from the sun, from which they derive their energy. It is probable that these have diminished gradually in the past; if so, then the forces of nature were at one time more vigorous than they are at the present day.

STAGES IN EARTH HISTORY.—The earth is thus assumed to have attained its present form and features, like a living organism, by a slow process of growth and development, and each stage in its history was necessarily dependent on those that went before, and left its mark on those that came after. From this it follows that the conditions which obtained during any period are not likely to have existed before nor to recur exactly at any later time.

COAL PERIOD.—An illustration of this may be found in the circum-

stances under which the world's great coal-supplies were laid down. The coal period was marked by a peculiar combination of conditions which prevailed over enormous areas of the earth's surface. Those conditions followed a prolonged interval of comparative quiescence, during which the denuding agents reduced large tracts to the state of an approximately level surface or peneplain. Slow oscillations of small extent and a gradual sub-

land attended the deposition of the measures, so that the shallow-water conditions necessary for the formation of coal were maintained throughout a long interval. Further, the climate was such as to permit a luxuriant growth of vegetation and its subsequent preservation from complete decay. This combination of conditions is unique in the earth's history; it had never occurred before and has never obtained since, except over limited areas and for a limited period; neither is it likely to recur in the future. Thus we see how intimately the commercial prosperity of many countries at the present day is connected with conditions which prevailed countless ages ago.

STORY OF THE EARTH.—It will be the aim of the succeeding chapters to trace the varied changes which our globe passed through before it attained to its present aspect. The story of the earth thus unfolded, based on the study of the rocks which form its surface. We have already seen how those rocks were formed, and how they have been brought to occupy their present positions as the result of movements in the crust of the earth. We have also seen how the relative order of formation of different rocks can be determined by their order of superposition, and by the remains of organisms which they enclose.

GEOLOGICAL RECORD—CHRONOLOGY OF THE ROCKS.—With the aid of these principles it has been found possible to arrange the various rocks which go to make up the earth's surface in the relative order of their formation, or, in other words, in order of age. Rocks of the same age have been classified into groups and given some distinguishing name based either on their lithological characters, their organic remains, or the locality where they are well displayed. These groups have been collected into larger groups for convenience. The arrangement adopted and the names given necessarily vary somewhat in different countries; but a general similarity of grouping underlies them all. The one usually adopted for British rocks, which, as a fact, include equivalents of nearly all the rocks forming the earth's surface, is subjoined (taken from J. E. Marr's *Principles of Stratigraphical Geology*).

GEOLOGY

SYSTEMS

| | |
|---------------------------|---|
| CAINOZOIC or TERTIARY. | Recent. |
| | Pleistocene. |
| | Pliocene. |
| | Miocene. |
| | Oligocene. |
| | Eocene. |
| MESOZOIC or SECONDARY. | Cretaceous. |
| | Jurassic. |
| | Triassic. |
| PALÆOZOIC. | Permian. |
| | Permo-Carboniferous (of certain extra-British areas). |
| | Carboniferous. |
| | Devonian. |
| | Silurian. |
| | Ordovician. |
| | Cambrian. |
| PRECAMBRIAN. | |

WIDE APPLICATION OF TERMS.—The systems may be divided into series, and the series into stages, which may be further subdivided to any extent according to local peculiarities. It is noteworthy, however, that the names which are given to the various groups in the above table of British rocks have a very general application, and, in fact, they can be, and have been, applied in a broad sense all over the world. This is significant, as showing the widespread nature of the changes which have affected the earth's surface in the past. For example, the system names Cambrian, Ordovician, Silurian are found to be applicable without difficulty to the older rocks of North America, and it has been frequently found that similar organic remains or *fossils* occur in Britain and North America, and succeed each other in the same order in these two widely separated areas. The identification of strata in two districts isolated by the sea or by other rocks is largely based on the fossils they contain, as the actual order of superposition cannot in those cases be observed.

GEOLOGICAL MAPS.—In most regions the distribution of the rocks of various ages and lithological characters have been laid down on maps; the boundaries between the different kinds are shown by lines, and the areas occupied by them are indicated by colours, or by a suitable system of shading or other conventional design. Such a map, on which the various rock types found in a region are separated off and indicated in a suitable way, is known as a **GEOLOGICAL MAP** (see coloured map of the rocks of the British Isles).

Before passing on to the earth history proper, it may be useful to indicate briefly the main lines of the story.

RECONSTRUCTION MAP
OF THE

WESTERN ISLES

Scale of Miles

ATLANTIC OCEAN



EARLY HISTORY

EARLIEST CONDITION OF THE EARTH.—In its earliest stage the earth was in a state of vapour or composed of small particles, which, under the influence of gravitation, and in order to oppose their aggregation, time enabled this to proceed, and when a solid crust was formed, surrounded by an atmosphere. The early stages of consolidation were probably marked by considerable volcanic activity when the crust was repeatedly broken up and renewed.

INITIATION OF DENUDATION AND DEPOSITION.—When the cooling had proceeded far enough for water to exist as such, denudation with attendant deposition was initiated. The water collected in hollows of the primitive surface, and in these hollows the first sediments were laid down. It is not likely that recognizable traces of those earliest sediments have persisted to the present day. There is probably a great gap in our knowledge of the beginning of sedimentation, and the succession of events which preceded the formation of the oldest deposits which have been preserved to us is matter of inference and speculation rather than of actual knowledge.

EARLIEST TRACES OF LIFE.—In the beginning of the Cambrian period we are furnished with evidence of life in the sea waters. The highly organized nature, relatively speaking, of the first undoubted organisms hitherto discovered leaves no room for doubt that they were the descendants of a long train of ancestors which lived in earlier seas, but of which few, if any, traces have been found so far.

ALTERNATING PERIODS OF QUIESCENCE AND DISTURBANCE.—From the beginning of the Cambrian period the records of the rocks become clearer, and can be read with some certainty. We know from their study that from that time onwards the surface of the earth has passed through long stages of comparative quiescence, interrupted by periods of great disturbance of the crust, which usually affected wide areas and produced radical changes, especially in the distribution of land and sea and climatic conditions. The Lower Palæozoic, viewed broadly, was a quiescent period marked by gradual subsidence of land areas at the beginning, and gradual emergence towards the end, culminating in continental conditions during Devonian times. Minor disturbances and irregularities on a small scale were not unknown, but their effects were comparatively unimportant. Continental conditions were succeeded by a quiescent phase lasting through the Carboniferous period. At its close an important uplift set in, with the

arms. The new theory postulates that the planets of the solar system had their origin in similar clots on a parent nebula of the spiral type, and that from the central core the sun was developed. At a later stage the central core and the clots became more distinctly separated, and gathered into themselves the scattered particles which surrounded them. From this stage dates the separate existence of the planets of which the earth is one.

LATER STAGES.—Let us now consider the later stages preceding the sedimentary record as stated in the new hypothesis. At first the planetary mass of the earth, which was growing at the expense of the matter in the space surrounding it, did not possess an atmosphere, for its mass had not increased sufficiently to hold one by attraction. Were it not for the attraction which the present earth exerts by virtue of its mass on the gases in the atmosphere these would fly off into space, and leave an atmosphereless globe. As the young earth continued to grow it became capable of retaining an atmosphere, but one much more attenuated than the present. It is known that many molten bodies can hold large quantities of gaseous matter, which they give off on cooling, and the atmospheric gases are supposed to have been derived by *occlusion* (as this phenomenon is termed) from the cooling materials of the earth. In this respect, again, this hypothesis stands in marked contrast to the Laplacian view.

TEMPERATURE IN YOUNG STAGE.—Another important feature of the hypothesis is the assumption that in the young stage the temperature of the earth was not excessively high, probably not high enough to fuse most of the constituents. Increase of temperature resulted from contraction and compression as the bulk increased, from chemical activity within, and from the falling in of new material. As a result, melting of the constituents occurred at first irregularly through the mass, and then became more general in the inner portions, while the outside was still a confused collection of particles which had been gathered up from space and had not been melted.

FIRST VOLCANIC EPISODES.—When melting occurred within, tongues of molten material were pressed into the outside fragmental zone and some reached the surface, thus giving rise to the first volcanic episodes. The volcanic action became more intense as the internal heat continued to increase by the above and other means, until the surface was made up chiefly of lava and fragmental material, while molten masses insinuated themselves here and there underneath the surface and later on consolidated. When the outside became sufficiently cool to allow of the condensation of

INCEPTION OF LAND AND WATER AREAS.—This hypothesis also offers what is perhaps the most reasonable account yet proposed of the initial stages in the separation of the surface into distinct land and water areas. At first the water collected into hollows distributed irregularly over the much-broken surface, but it is supposed that from various accidental causes these hollows were relatively more numerous in some places than others, so that, taking broad tracts into consideration, some would have more water areas as compared with land than neighbouring ones.

It is known from the behaviour of the ordinary agents of weathering that the heavier materials are removed in solution more rapidly than the lighter ones. As soon, therefore, as weathering began to operate, the removal of a greater proportion of the heavier constituents from the land to the water tracts left the former somewhat lighter and the latter heavier than before. It is supposed that this caused the aqueous tracts to sink with respect to the land, whereby more water flowed into them, thus increasing the weight and subsidence still more. By a repetition of these processes the smaller areas gradually united into larger ones, until the surface was marked by continuous sheets of water of considerable size separated by tracts of land. The origin of oceanic basins is therefore assigned to a very early stage in the history of the earth, and it is considered that from that time to the present the positions of the deeper parts of the modern oceans, especially the Pacific, have not altered materially, so that if a borehole could be put down under those parts there would be found in succession representatives of all the deposits formed since the beginning of sedimentation. From the time when the oceanic basins were originated, and denudation began to operate, the subsequent history of the earth proceeded along more or less familiar lines down to the present day.

SPECIAL CHARACTER OF EARLY STAGES—LIFE.—The chief difference between that early period and the present lies in the fact that nowadays the products of volcanic activity bear but a small proportion to those of denudation, whereas then the reverse was the case. There is yet one important event to chronicle; at some stage or other there was a beginning of life. It is not known how it originated, nor when and where it first appeared, for the earliest traces met with in the rocks show that it had

then attained to a considerable degree of complexity. According to the generally accepted theory of evolution this implies that life had existed for a very long period of time before it could have developed to that stage. Nothing is as yet definitely known of the earlier condition of life on the

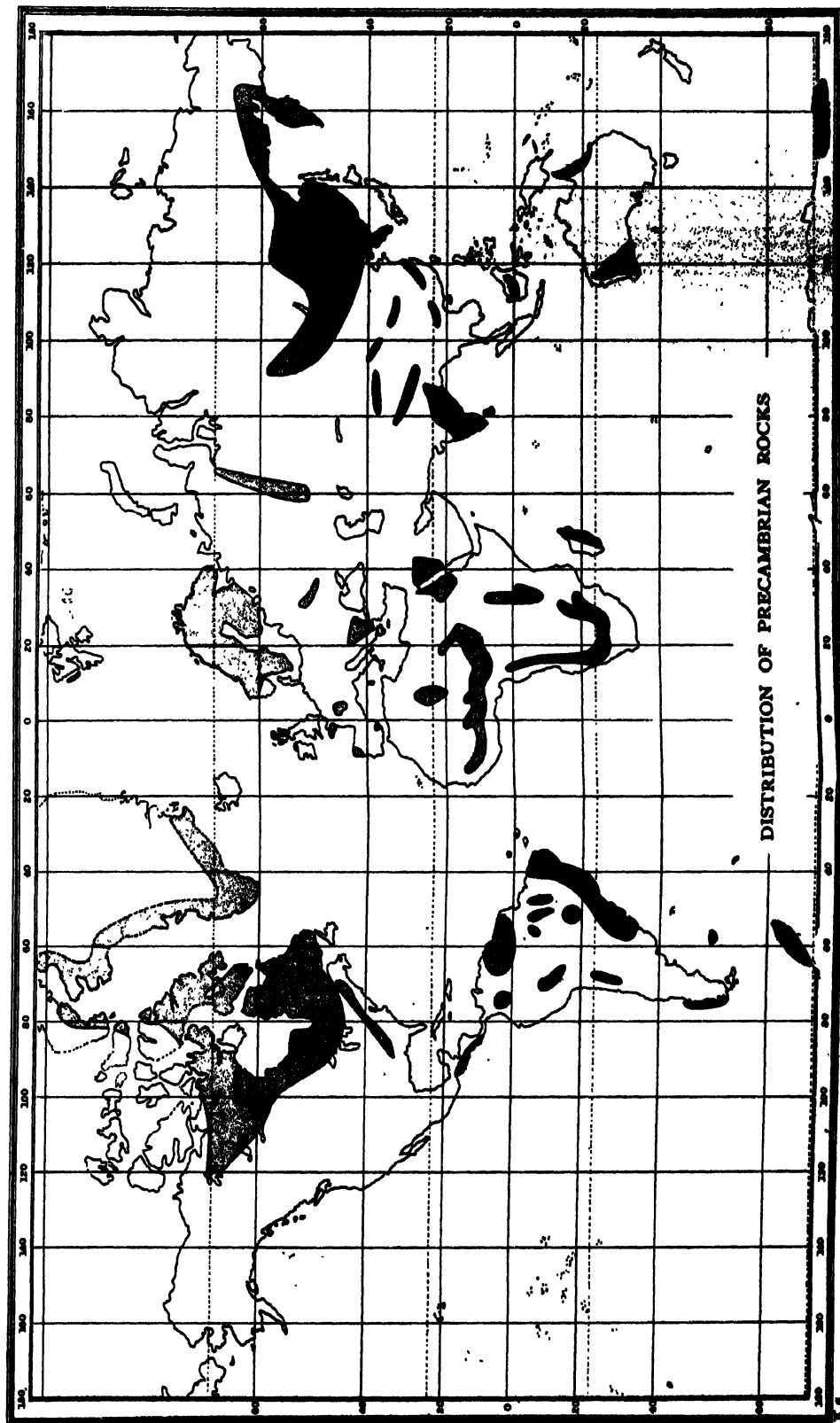
CHAPTER VI

FIRST CONTINENTAL (ARCHÆAN) PERIOD. FIRST MARINE (OLDER PALÆOZOIC) PERIOD

THE PRECAMBRIAN OR ARCHÆAN PERIOD

DISTRIBUTION AND CHARACTER OF THE ROCKS.—The oldest rocks met with in the surface of the Earth are assigned to this period. They have a wide distribution in every continent (see plate), and also underlie at no great depth the rocks of the sedimentary series, which only form a relatively thin skin above the old fundamental rocks. Their characteristics are sufficiently pronounced to mark them off as the products of a special period. For the most part they consist of what are known as CRYSTALLINE and FOLIATED rocks; most of the former are made of mineral grains or crystals which have formed in the rock as it cooled from a molten state; the latter are of various origins, and their peculiar characters have been impressed upon them by intense movements which have rolled them out, crushing the original minerals and causing new ones to develop in parallel bands—hence the origin of their striped, banded, or foliated appearance. In some crystalline and foliated rocks the minerals have been developed from pre-existing minerals under the action of intense heat (*thermal metamorphism*).

CONDITIONS OF FORMATION.—The conditions under which they were formed were also peculiar. Many of their characteristic minerals can only be produced under the action of great heat, and they must therefore have been formed either at a stage in the history of the earth when the temperature was high, or at a great depth underneath the surface. Many of the crystalline rocks can be proved to be INTRUSIVE masses, *i.e.* they were forced from below in a molten state into overlying strata, which were highly disturbed, baked, and even melted in the process. It is probable that they never reached the surface, but cooled slowly at great depths. In several



The shaded portions show the chief areas where these rocks are exposed at the present day. The boundaries are only approximate.
(After de Lapparent.)

cases they are the remnants of deep reservoirs which supplied the material welling out at the surface in volcanoes.

Many of the foliated and some of the crystalline rocks appear to have been at one time ordinary sediments, but so changed are they from their erstwhile condition that their original state is often difficult to make out. The minerals which they contained as sediments have been entirely destroyed and replaced by totally different minerals formed under the influence of high temperatures and intense pressures. It is known that such changes can occur in sediments, for they have taken place in later periods near large masses of intruded rocks, such as the granites of Bodmin Moor, Dartmoor, and other places in Devon and Cornwall and elsewhere. These are surrounded by a ring of finely crystalline and banded rocks, the passage of which into ordinary sediments can be clearly traced.

The Precambrian rocks, as a rule, bear evidence that to them high temperatures intense pressures have operated upon them. They were twisted, crumpled, and shattered to an almost incredible degree (see fig. 32). The existence of such pressures in itself points to their having been formed at great depths, and their presence at the surface must therefore be the result of considerable upheaval followed by long-continued denudation. As these rocks had very much their present aspect before the beginning of the Cambrian period, one gains some idea of the length of time during which the agents of denudation must have been at work; but of the resulting deposits only those formed under continental conditions towards the end of the period have been preserved to us.

The Precambrian rocks are frequently spoken of as if they represented the rocks of the primitive surface of the earth. This is not probable, for, as has been said, many of them are intrusive masses, and therefore they must have been intruded into something which was above them; moreover, it is difficult to believe that the violent contortions of the foliated rocks could have been induced except under the pressure of a great thickness of some cover.

ARCHÆAN AND YOUNGER ROCKS.—The Cambrian sediments rest directly on the crystalline rocks, and their lower strata contain pebbles derived from those rocks which show that they had been brought to much their present state, and moreover had been exposed by prolonged denudation of the overlying cover, before the sediments were formed. Certain sediments attributed to the later stages of the Precambrian period have been referred to above; they resemble in most respects those formed under continental conditions in later times; they are mixed with volcanic material and rest directly on crystalline rocks. It is claimed that traces of organic

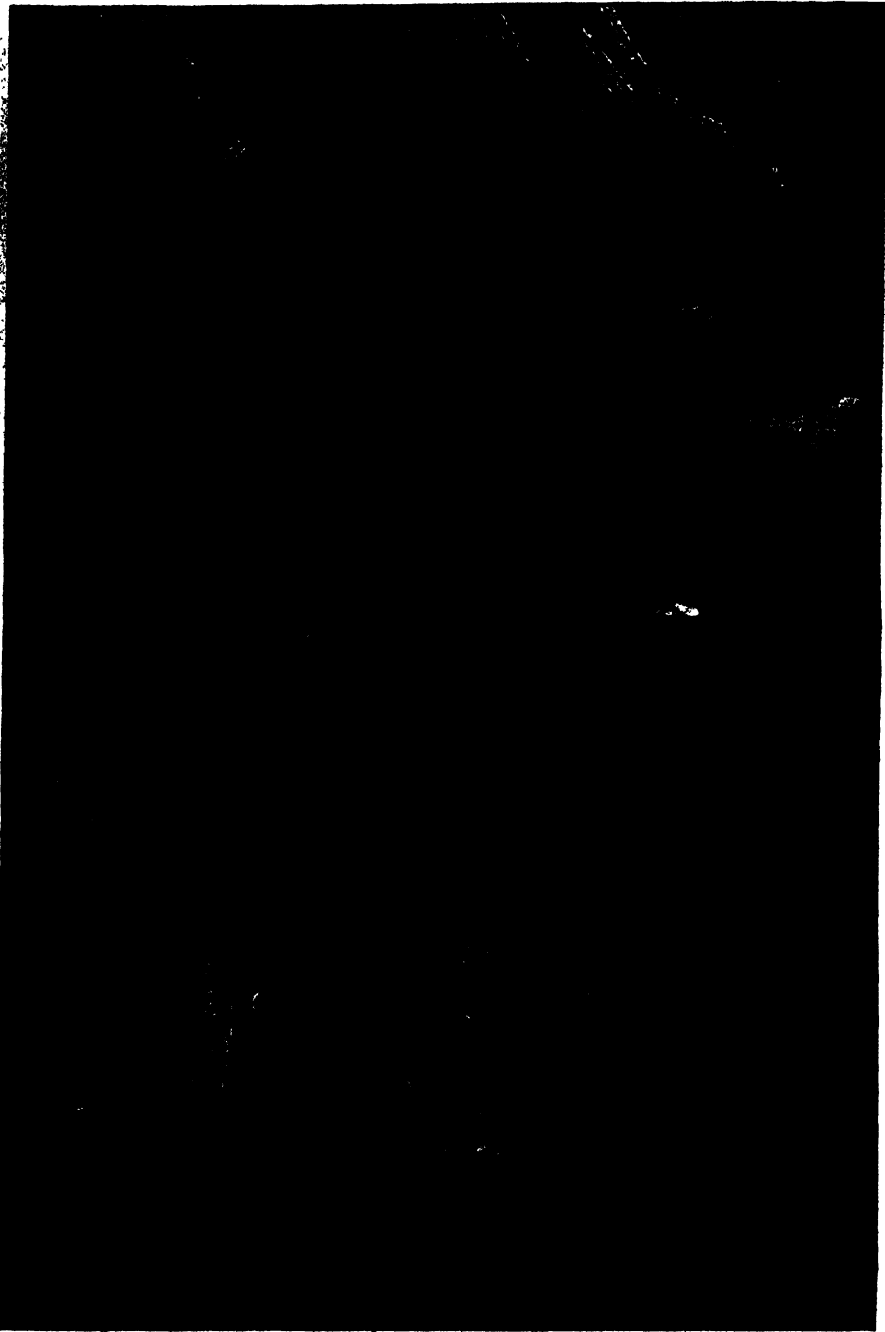


Fig. 3a.—Contorted Schists (probably Precambrian). After J. Geikie

remains have been observed in them, but as yet they are imperfectly understood.

DISTRIBUTION AND ECONOMIC IMPORTANCE OF ARCHÆAN.—The large area occupied by the Precambrian rocks is indicated on the accom-

panying map, from which it will be seen that they form a large surface in every continent; in addition to this they underlie later rocks to a very small depth over wide regions. They are of great economic importance as their position is such that they are the source of the water which is the life-giver of the world. During their formation they were the source of the water which was accumulated in the oceans, so that the water is not obtained from those rather than from the parent rocks.

FIRST CONTINENTAL PERIOD.—The oldest rocks point therefore to great earth movements, with attendant mountain-building and subsequent denudation, in the period preceding the formation of the oldest Cambrian strata. That this movement was a widespread one is shown by the great extent of land composed of these rocks which existed at the beginning of Cambrian times. The Precambrian may therefore be spoken of as the *First Continental Period*. At its height, when the earth movements had reached their greatest intensity, the surface of the earth must have been highly irregular, but before Cambrian times prolonged denudation had removed the irregularities and smoothed down the surface almost to a plain; it is probable that many areas of Precambrian rocks have never been subsequently submerged; they have therefore suffered the denudation of all succeeding periods in addition.

SCENIC FEATURES OF ARCHÆAN REGIONS.—For these reasons the regions occupied by the oldest rocks are characterized not by great altitudes and rugged features but by a moderate altitude and smooth undulating outlines, while mountain chains in the true sense of the word are absent. It is true that a country such as Norway, which is made up almost entirely of these rocks, may be described as a mountainous country, but there are no true mountain chains. The mountains have arisen from the carving out of valleys in a plateau of the old rocks which was uplifted to its present height at a recent period. When Norway is viewed from the west it presents an extremely rugged aspect, but when the mountains are ascended, and the highest point is reached, the appearance changes to that of an immense plain carrying numerous shallow lakes on its surface, and furrowed here and there by deep valleys. All the mountain tops come to a uniform level and there stop; if, therefore, the valleys and hollows are filled in, and the tract thus restored to its condition before denudation had acted on it, an almost level plain of great extent and sloping gently to the east would be the result.

The plateau character is exhibited to a more marked degree by the

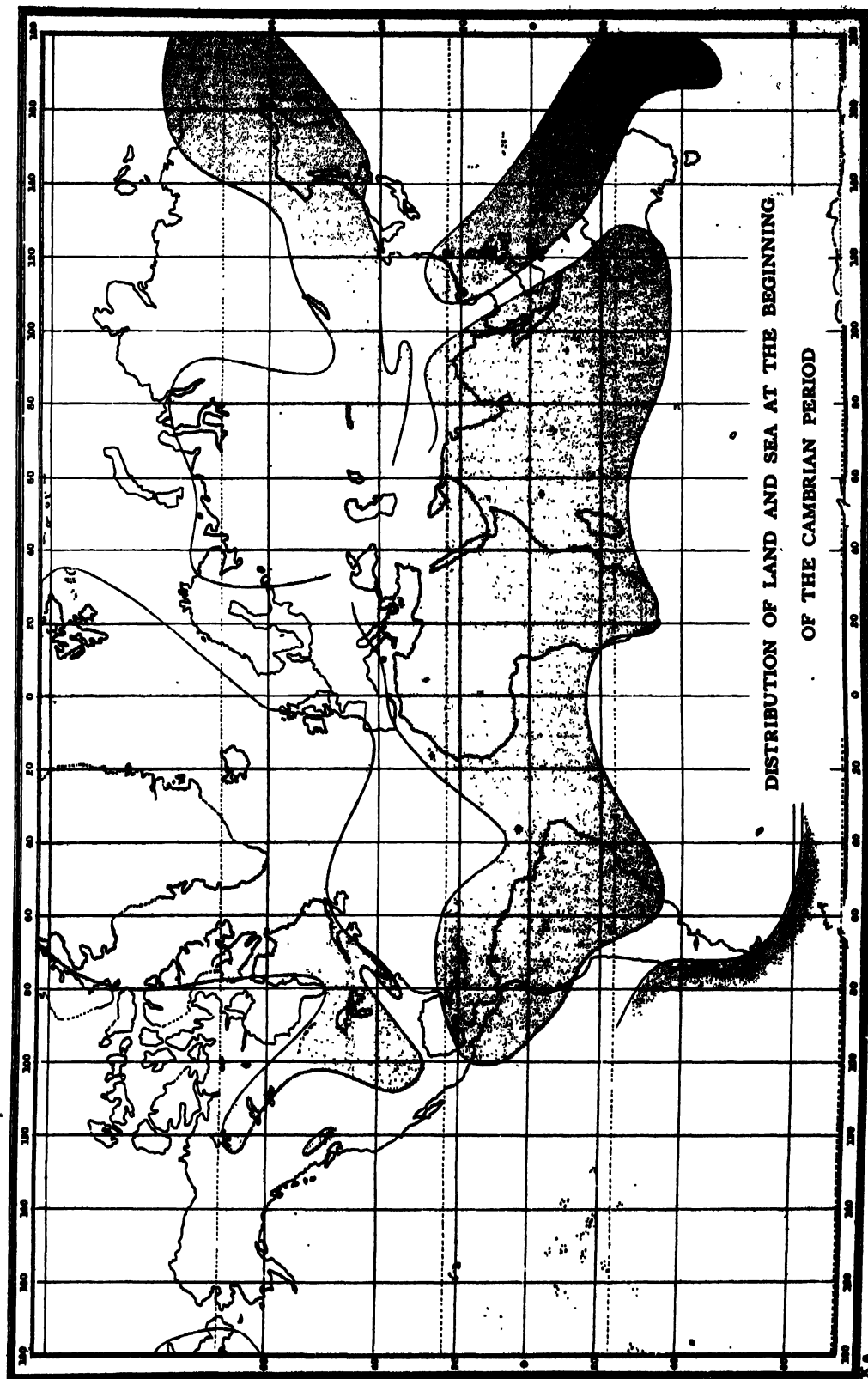
region around the great lakes of North America. It is an illustration of the general principle that the most rugged outlines are found in regions composed, not of the oldest rocks, but of those which have been affected by earth movements in comparatively recent times, where denudation has not acted on them for a sufficient length of time to wipe out the irregularities produced by those movements.

It is probable that red and green sandstones, conglomerates, and shales, such as the Torridon of north-west Scotland, the Longmynd rocks of Shropshire, and similar rocks in Norway and North America, were laid down in inland basins towards the end of the first continental period, but as yet no marine deposits are known with certainty, so that the extent and positions of the land areas can only be approximately guessed at.

FIRST MARINE (OLDER PALÆOZOIC) PERIOD.—A gradual but widespread submergence brought the continental conditions to a close and ushered in the first marine period, which lasted, with a few minor interruptions, to the end of Silurian times. Stated broadly, the earliest Palæozoic rocks were deposited during the initial shallow-water phase in a gradually deepening sea, while the later sediments show the effects of the progressive shallowing which culminated in the Second Continental Period at the close of the Silurian.

CAMBRIAN PERIOD.—As considerable interest attaches to the conditions under which the earliest undoubted marine sediments which have been preserved to us were laid down, an attempt will be made to indicate the probable state of the earth's surface at the beginning of the Cambrian period, in so far as this is made possible by a study of the character and distribution of the strata and of the organic remains, or, in other words, to restore the geography of that remote period. Not only will this serve to illustrate the method by which the geographies of the past are ideally reconstructed, but it will bring their comparison with modern conditions forcibly before the reader.

The **DISTRIBUTION** of the Cambrian rocks is almost world-wide, and the earliest sediments are everywhere characterized by peculiar organic remains which render it a matter of no great difficulty to identify these strata in different parts of the world, however distant they may be. Cambrian rocks occur in force in various parts of northern and southern Europe and North America, and have also been observed in Argentina, India, China, Australia, and Tasmania. As the name of the system suggests, they are exceptionally well developed in Wales, where they were first carefully studied and divided into various groups, to which local names were given after the places where they are typically dis-



played. As similar rocks came gradually to be identified in various parts of the world, the local Welsh names were extended to them also, and thus we hear expressions such as the Tremadoc rocks of the State of New York, or of Argentina, but recently, and more especially in America, there has been a tendency to displace the British names in favour of local terms.

EARLY CAMBRIAN SEA.—The rocks on the whole are such as would be laid down in an open ocean, and the fossils support this view, so that where Cambrian strata are now visible it is safe to infer that those places were then under the sea. But the extent of that sea was much greater than the area where these rocks now occur at the surface. In the first place, large tracts of sediments have been removed by denudation, while others have been covered over by later deposits and hidden from view; and, lastly, parts of the floor of the early Cambrian sea may have remained under water from that time to this, in which case the deposits have been covered over by those of all subsequent periods. The relation between the present occurrences of these rocks and their probable distribution in the past is well shown in the map of North America (fig. 33).

The limits of the early Cambrian sea must therefore be discovered from other data than the present distribution of the sediments, and to this end the character of these must be studied. We have already seen that near the shore and the mouths of rivers at the present day coarse sand and gravel are laid down; while farther out to sea are the finer sands, clays, and muds, or, if conditions are favourable, calcareous deposits may be formed. The kind of rocks, and their relative fineness, afford, therefore, a clue to the distance from the shore line at which they were laid down.

If we apply this to the Cambrian rocks of northern Europe and North America, we find there is a remarkable agreement between the two sides of the Atlantic. The Welsh deposits are probably about 12,000 ft. thick, and consist largely of sandstones and conglomerates (once sands and shingles), which indicate proximity to a shore line, and it is indeed probable that this lay not far off the coast of Wales. Along the Welsh borders the sediments are finer-grained and of smaller thickness (about 3000 ft.), which suggests an increasing distance from the shore.

This suggestion is borne out by the rocks in the north-west Highlands of Scotland, which are still thinner, and contain much calcareous matter; while if we pass to Scandinavia, the 12,000 ft. of sediments in Wales are represented by extremely fine black shales and limestones of a total thickness not exceeding 400 ft.—an attenuation which becomes still



Fig. 33.—Map of North America, showing the Outcrops in black of Early and Middle Cambrian Formations. The areas shaded by lines represent regions where the formations are believed to exist, though not exposed; broken lines indicate uncertain areas. The unshaded areas north of Mexico are believed to have been land during the early portion of the Cambrian period; the unshaded area south of the United States represents lack of knowledge. The light shading about the borders of the land indicates the continental platform of the modern continent.

more marked on passing east into Russian territory. This thinning towards the east, and the incoming of fine sediments and limestones in that direction, accords well with the view that the shore line lay to the

west. A similar easterly thinning may be observed in comparing the Cambrian rocks of Bohemia with the corresponding strata as developed in Brittany.

On the west side of the Atlantic the conditions were reversed, for it is found that in parts of eastern North America the sediments are coarse and of great thickness, while farther inland they are much attenuated, and consist of fine shales and limestones, from which it may be inferred that on that side of the Atlantic the shore line of the Cambrian sea lay somewhere not far off the present coast.

EARLY CAMBRIAN LAND.—It follows that the North Atlantic was at that time occupied wholly or in part by a land area, from which the European sediments on the east and the North American on the west were derived (see plate). This early continent has been spoken of

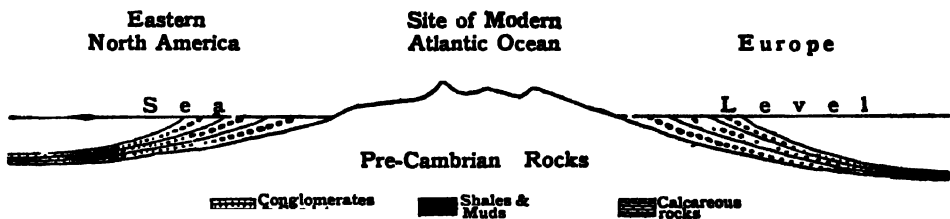


Fig. 34.—Diagram illustrating the relations of the Cambrian Rocks of North America to those of Europe.

sometimes as Atlantis (fig. 34). The central parts of North America, however, are believed to have formed a land area of great extent, to the south of which the sea margin extended continuously from the east coast to the Rocky Mountain region of the west. This may be compared with the eastern Russian region, which was also a land area at the time, while the western and southern regions were under the sea; the central region of China was probably another extensive land area.

YOUNGER CAMBRIAN.—Passing now to a consideration of the higher Cambrian strata, it is found, in the first place, that they are finer grained than the lower, and contain more calcareous rocks; in the second place they have, on the whole, a wider distribution; they often occur, especially in the south of the United States, resting on old rocks, where no lower Cambrian exists; this is known by geologists as an **OVERLAP** of the higher strata over the lower. Both the distribution and the nature of the sediments point to a deepening of the sea during the period, and to the extension of the shore lines as more and more of the land became submerged.

CAMBRIAN CLIMATE—EVIDENCE OF CONDITIONS.—The similarity of the sediments as a whole to those formed in subsequent periods, even unto the present day, shows almost conclusively that the conditions under

which they were deposited were, in the main, of the same nature as those which have prevailed since; but as there are no means of ascertaining the rate at which they were formed, one cannot infer whether denudation was more rapid then than now. One peculiarity of those sediments is the large proportion of felspars which the coarser kinds contain. In temperate climates, at the present day, this mineral is readily decomposed by the chemical action of water and carbon dioxide; but in arid regions, where such action may almost be neglected, they are not decomposed,

and their grains become mixed in the sediments with those of quartz and other minerals. It is therefore possible that the climate on the continents bordering the early Cambrian ocean was somewhat arid.

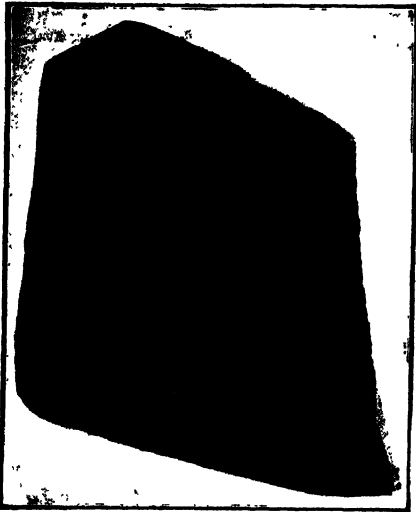


Fig. 35.—Scratched Stone from the Glacial Beds at the base of the Cambrian in China (Willis)

Another line of evidence bearing on the climate of the period is afforded by some deposits found in Norway, near the Varanger Fjord, on the Yang-tse River in China, and in South Australia. In all cases they probably lie at the very base of the Cambrian system; they contain large boulders, scratched and polished precisely like those which occur in the deposits left by modern glaciers, and they rest on

a smooth scratched surface, also resembling one over which glaciers have passed (fig. 35). It would appear from this that glacial conditions certainly prevailed at these widely separated places at the very beginning of the Cambrian period. The mean temperature of the earth could not therefore have been widely different from that of the present day, and the arid conditions suggested by the preservation of the felspar grains in the rocks were probably due to local causes.

It has been mentioned that the Cambrian rocks of west and north Europe strongly resemble those of the Atlantic border of North America; the resemblance is indeed closer than with those of southern and central Europe, which in turn are more allied to the corresponding deposits of the southern and western United States. It has been argued that this indicates a difference between the climates of the northern and the southern areas—that, in fact, there were climatic belts in existence then as now. This question is difficult to decide one way or another. The general

resemblance of the Cambrian fossils everywhere appears to point, on the other hand, to equable climatic conditions over the whole globe.

The Cambrian period was one of little volcanic activity, at any rate in the submarine areas. Sheets of lava found between normal sediments prove occasional eruptions under the sea, but more frequently beds of ash may be observed which indicate that there were active volcanoes on the land; some of the ash blown out from these was scattered over the surface and subsequently washed into the sea along with other detritus, while some of it fell into the sea directly and settled to the bottom. It has frequently happened that sheets of igneous rock have been forced from below into the strata long after they were deposited, and it is not always easy to distinguish between these intruded sheets of later date and true lava flows formed at the same time as the strata among which they occur. The test applied where possible is: whether the strata are hardened or baked above *and* below, or only below. If the former holds, the strata must have been there before the igneous rock; if the latter, the lower beds were there, but the upper had not been laid down.

LIFE OF THE CAMBRIAN PERIOD.—It is known from direct evidence that life of some kind existed prior to the beginning of the period, but the remains of it are scanty and imperfectly understood. Further, if the tenets of the theory of evolution are accepted, it follows that, as the organisms of the Cambrian seas were descended from a long line of ancestors, a correspondingly long time must have elapsed during which those ancestral forms lived and developed. It is a remarkable fact that all the great groups of the animal kingdom, except the vertebrata or back-boned animals, are represented among the Cambrian fossils. The majority of them, however, show clearly that they are but early types, from which were descended in later periods others better adapted to take advantage of their surroundings in the all-important matters of obtaining food and defending themselves against their enemies.

ORDOVICIAN PERIOD.—It has been said that during the later stages of the Cambrian the land was gradually sinking beneath the sea, and that finer sediments and limestones were laid down where at one time had been shallow sea with its sands and shingles, or perhaps even a land area. During the succeeding Ordovician period the submergence continued and reached a climax towards the middle, when deep sea prevailed over the greater part of the early Cambrian shore and extended over much of the Cambrian land. Afterwards the character of the sediments shows that a slow and progressive shallowing set in which became more marked in the succeeding Silurian period.

CHARACTER AND DISTRIBUTION OF ORDOVICIAN ROCKS.—A striking character of much of the finer-grained Ordovician sediments is their black colour, due probably to the admixture of a large amount of carbonaceous matter. It has frequently led to the expenditure of much time and money in futile attempts at finding coal in these rocks. Like the Cambrian strata, they exhibit the same tendency to become thinner, finer-grained, and more calcareous in passing from west to east, or, more correctly, from south-west to north-east, which points to the continued existence of part of the old land area towards the west; the corresponding deposits of eastern North America are characterized by great deposits of limestone made up of organic remains. It is possible that by this time the continental area which occupied the North Atlantic had been worn down to a small elevation, and that the supply of mechanical sediment was becoming limited, and therefore a clear sea would result, enabling the calcareous organisms to live and thrive.

The difference between the north and south European regions of this period was more pronounced than in the Cambrian. The former type, both of rocks and organisms, was the general one, and spread over such distant areas as Asia, North and South America, and Australia; the latter type was more local, being confined to southern Europe. In the Irkutsk region of northern Asia the Ordovician rocks are developed as red beds of continental type, which are associated with deposits of rock salt.

VOLCANIC ACTIVITY.—Over certain tracts of the European area there was prolonged volcanic activity at two distinct periods. Massive flows of lava and thick beds of volcanic ash occur among the normal sediments, hence eruptions must have occurred on the land as well as under the sea. The volcanic materials, being hard and resisting, exercised a profound influence upon the scenery of the regions occupied by these rocks when at a much later stage they were uplifted to form dry land; indeed their influence has not yet ceased to make itself felt, for the rugged character of much of the western part of the British Isles, especially of North Wales and the Lake District, is directly traceable to them. The hard lavas and compacted ashes lying among the softer sediments resist denudation and stand up as ridges and peaks, while the surrounding strata are carved out into valleys and hollows.

The close of the Ordovician period was marked by relatively coarser sediments, indicating a progressive shallowing of the sea over parts of northern Europe and North America; it may be regarded as a minor disturbance in the Lower Palæozoic marine period. In North America the Ordovician rocks were uplifted above sea level over considerable areas,

and occasionally slightly folded and exposed to denudation. The elevation was followed everywhere by a depression at the beginning of the succeeding Silurian period, whereby the uplifted and denuded rocks were once more covered by sediment. In Britain the movement was chiefly confined to the borders between England and Wales, and its chief importance lies in the fact that it was prophetic of the more extensive disturbance affecting these and wider regions at the close of the Silurian.

SILURIAN.—The Silurian deposits show in a somewhat marked degree the difference between shore or shallow-water conditions and open-sea conditions, which are represented by two different types of sediments. The first type consists of relatively coarse sandstones, and conglomerates, with limestones derived almost exclusively from the remains of reef-building corals, and therefore necessarily formed in shallow water, as these organisms cannot thrive at a depth. In the second type black shales predominate; the carbonaceous matter to which they owe their colour was probably derived from the organisms called *graptolites*, which flourished in the surface waters of the deeper parts of the ocean, and whose remains after their death showered down to the sea-floor in countless profusion. The deep-water conditions were, however, somewhat more restricted than in the Ordovician, and there is an evident preparation, which becomes more and more marked in the later stages, for the approach of continental conditions once more.

EARTH MOVEMENTS AND MOUNTAIN-BUILDING.—In the European region important earth movements, accompanied by the formation of mountain chains, brought the Silurian period to a close. The strata, especially of Scandinavia and North Britain, were thrown into ridges and troughs having a general north-easterly and south-westerly direction. The movements are of interest on account of their influence on the deposits formed during the preceding and succeeding periods. The soft sediments deposited during the great Lower Palæozoic marine phase were consolidated and hardened, while intense pressure, such as generally accompanies mountain-building, had the effect of rearranging the particles of the rocks, so that they set with their greatest length parallel to the direction of the pressure.

CLEAVAGE.—When a rearrangement of this kind takes place throughout a mass of rock, it shows a tendency to split in that direction more readily than along the bedding-planes. These new planes of division are known as **CLEAVAGE-PLANES**, and are usually quite independent of, and transverse to, the bedding-planes. The amount of cleavage depends on the intensity of the pressure and on the grain of the rock; in shale or

mud it reaches great perfection if the pressure is sufficiently great. Splitting can then only be induced along the cleavage-planes, for the bedding-planes are usually obliterated, and cannot be detected unless there happened to be thin beds of a different grain or of different colour in the original sediments.

SLATES.—When a rock is well-cleaved and of suitable grain, it can be split into the large, thin slabs known as **SLATES**, which are used mainly for roofing. The quality of the slates depends upon the perfection of the cleavage and on the power of the rock to withstand the atmospheric agencies without cracking or decomposing. Coarser-grained varieties, which can be split only into relatively thick slabs, are known as **FLAGS**, and are used for flooring and other purposes. It is probable that much of the cleavage which has affected the Palæozoic rocks of north-west Europe was developed by the folding movements at the end of the Silurian period.

NORTH AMERICAN SILURIAN.—There is no evidence that mountain-building occurred at this date in North America, but the succeeding deposits indicate that important changes in the relation of land and sea had taken place. The marine area suffered great restriction during the Silurian period, and much new land appeared over the North American area. The elevation was accompanied by the formation of extensive lagoons or inland lakes, where the connection with the sea was partly or entirely cut off, and where evaporation proceeded at a great rate.

The water then became successively more saline by the concentration of the mineral salts which were held in solution in the sea water, and of those carried in by such streams as flowed into the lagoons. Ultimately these were deposited, with the formation of extensive beds of rock salt and gypsum (both of which are present in sea water), which alternate with thick layers of red shale and limestone (probably a chemical precipitate), pointing either to incursions of salt water at intervals, or to the supply of fresh water carrying sediment from the land being greater than evaporation could remove. The deposits of rock salt in the Silurian tracts of North America are of considerable economic value at the present day.

CHAPTER VII

SECOND CONTINENTAL PERIOD AND MARINE PHASE—DEVONIAN AND CARBONIFEROUS

DEVONIAN PERIOD.—This period is interesting from the evidence it affords of the peculiar conditions under which the deposits were formed. As already mentioned, the Scandinavian and north British regions were theatres of mountain-building at the close of the Silurian period; but during that time the south of Britain was for the most part under the sea, and receiving the sediment washed down from the new-formed mountains in the north. As the tops of the anticlines became exposed to denudation, the sediments were swept off into the intervening hollows, which in some cases were probably without free connection with the ocean. In those hollows deposits of a peculiar character were formed, consisting mainly of soft bright-red muds, usually called **MARLS**; these are associated with coarse conglomerates which represent the gravels washed down by torrential waters from the bordering land.

AREAS OF DEPOSIT.—The prevailing red colour of the great mass of the deposit points to its formation in isolated areas where evaporation was comparatively rapid. In the northern region they were laid down on the upturned and planed-off edges of the older rocks; but towards the south, where the influence of the movements failed to penetrate, they probably succeeded the Silurian without any gap (though this is not quite certain in South Britain). There the deposits are marine in character, consisting of shales and muds, with important masses of shelly and coral limestone, but there is also an important development of red muds, pointing to abnormal conditions during their formation.

The **BRACKISH-WATER** or **FRESH-WATER TYPE** is confined to certain parts of Britain, Scandinavia, and North America, where the deposits are relatively coarser (see plate); they are finer grained towards the south, and masses of limestone become more frequent, increasing in importance towards southern and central Europe. The red muds and coarser sediments believed to have been formed under brackish-water conditions are known collectively as the **OLD RED SANDSTONE** rocks, while the name **DEVONIAN** is commonly restricted to the more normal marine types. It is interesting as another example of the close connection of the geological history of North America with north-west Europe that the two types are found there, and the deposits on the whole bear a striking resemblance in the two areas.

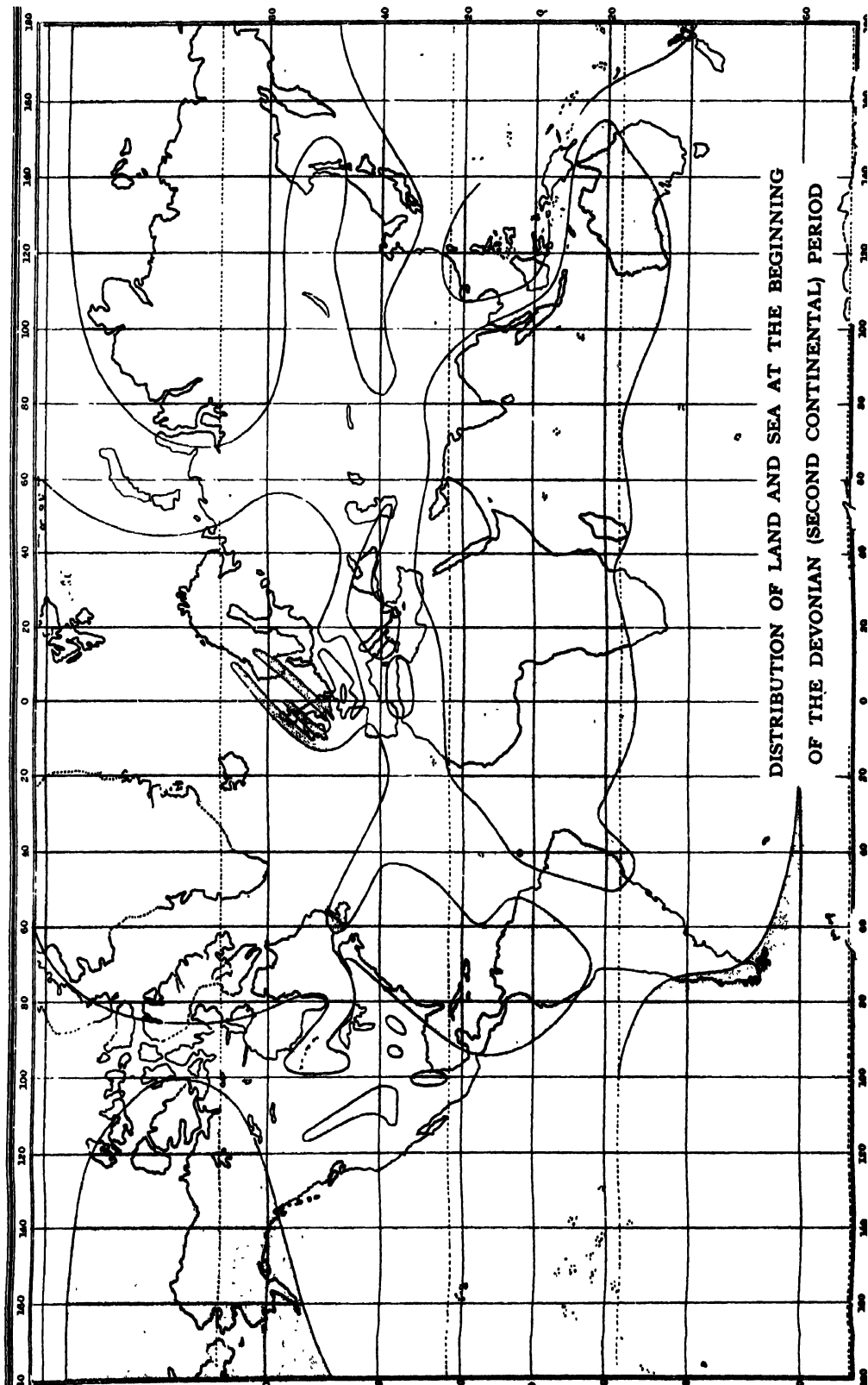
The MARINE SEDIMENTS are extremely widespread, being well developed in Asia and north-west India, and probably over a large area in Africa; also they attain great importance in South America, Australia, and New Zealand. Two distinct provinces can be recognized, but it is not known from what causes the difference between them arose. The northern includes the greater part of Asia, Europe, and North America; the southern one comprises South Africa, South America, and the southern part of North America, possibly also New Zealand and Australia. From that time, therefore, dates that close connection between the history of the great southern continents which became so marked in later times.

Towards the middle of the Devonian period there was a great extension of the sea over the land, and consequently those rocks have a wider distribution than the Lower Devonian, and frequently rest on various older rocks which formed the land in the earlier stages. Continental conditions still persisted in parts of Europe and North America, and in the former region there was renewed movement. It is probable that before the end of the Devonian the continents had been reduced by denudation to the condition of peneplains, and the supply of sediment was therefore limited; the early Devonian rocks were to a certain extent derived from the denudation of the Post-Silurian land, but in the later stages that also had been greatly lowered in height, partly by denudation and deposition and partly by gradual subsidence. Accordingly the higher Devonian rocks are finer-grained, and contain a large proportion of organic limestone formed in clear waters.

VOLCANIC ACTIVITY.—The region affected by the Post-Silurian movements was one of considerable volcanic activity during the Devonian period. Great thicknesses of lava and ash from submarine and terrestrial volcanoes became mingled with the sediments, and large masses of molten rock were intruded from below into these and earlier-formed strata. The volcanic materials exercise a profound influence at the present day upon the scenery of the regions where they occur.

ECONOMIC PRODUCTS.—From the economic point of view the Devonian rocks are of great importance. In Europe they carry valuable mineral veins from which lead, zinc, tin, silver, and other metals are obtained. In America they form the most important reservoirs of oil and gas, and occasionally phosphates—of commercial importance as manure—are found in them in great abundance.

TRANSITION TO CARBONIFEROUS.—The transition from the marine Devonian to the succeeding Carboniferous period seems to have been a gradual event all over the world, while by slow subsidence the Old Red



DISTRIBUTION OF LAND AND SEA AT THE BEGINNING
OF THE DEVONIAN (SECOND CONTINENTAL) PERIOD

Sandstone continental and brackish-water conditions gave way to the extensive though shallow-water seas in which the early Carboniferous sediments were deposited.

CARBONIFEROUS PERIOD.—This period has exercised a more profound influence upon the development of the human race than probably any other. Reasons have been given for supposing that from a geological point of view this period was unique. As we have already seen, certain areas in the Northern Hemisphere had remained above the sea throughout a very long interval, and no movements of great importance had occurred beyond a gradual elevation and subsidence, whereby the sea was rendered shallower or deeper and the extent of the land area increased or diminished.

Denudation must therefore have reduced the greater part of the land to the condition of a peneplain, where the streams could do no more work in transporting sediment, and the only agents in operation were slow solution and wear along the sea margins. It is true that at the end of Silurian times mountain-building occurred over a relatively limited region in northern Europe, but the rapid denudation which seems to have been characteristic of that region during the succeeding Devonian period had the result of levelling off the mountain ridges and filling up the hollows with sediment. Hence it is probable that at the beginning of the Carboniferous period extensive regions had been reduced to a low elevation above sea level, whereby a subsidence of small amount would cause a large area of land to be submerged.

MARINE PHASE.—In the Northern Hemisphere the subsidence began towards the close of the Devonian period, and the first Carboniferous deposits were laid down in a shallow sea. In more southerly areas there seems to have been but little change from one period to the other. The shallow-water phase was followed everywhere by open-sea conditions, but the depth was probably nowhere very great. On account of the low level of the bordering land area the supply of sediment brought down by the streams was limited, and hence there resulted clear water in which certain organisms such as corals and crinoids were able to live and thrive. This was a phase when the deposits were mainly composed of the remains of calcareous organisms; on hardening and compacting, they became massive beds of limestone, practically free from land detritus.

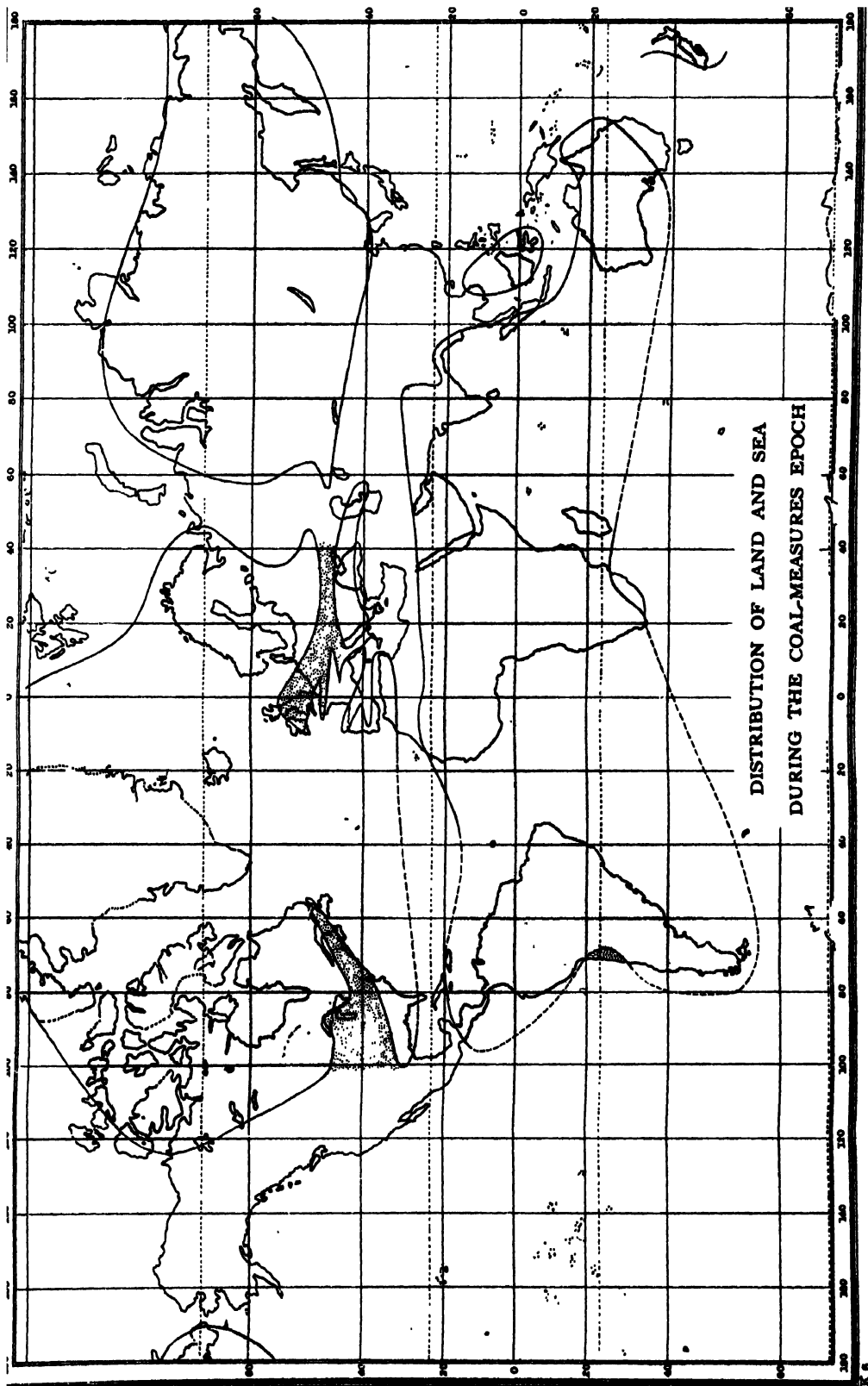
TRANSITION PHASE.—This phase was followed over a widespread area by a curious change of conditions when an entirely different set of strata was formed. Calcareous sediments gave way to deposits of well-rounded pebbles of vein quartz, free from calcareous matter; in other areas, presumably at greater depths or at a greater distance from a shore line, the

pebble beds were replaced by a great thickness of black muds. It is not quite clear how this change was brought about. There is no evidence of violent earth movements to account for it, and such small disturbances as occurred at intervals do not seem adequate to have produced such an abrupt and important change.

However it occurred it seems certain that a land area was then under the influence of vigorous denudation. From the nature of the sediments derived from it, it is inferred that this area was composed mainly of shale traversed by veins of quartz—"spar" along cracks, joints, and faults. Destruction of such an area would yield just the right materials, and as the beds of black shale which in one district appear to represent the pebble beds of another are relatively very thick, it is probable that the proportion of "spar" veins to the total amount of material removed was comparatively small. The perfect rounding of the pebbles suggests that the source was a considerable distance away.

SWAMP FORMATION.—Deposition of such strata continued until enormous areas had been to a large extent silted up and reduced to the condition of a swamp, with lagoon-like expanses, into which decayed vegetable matter and mechanical sediments were carried. On this swamp and on the borders of the surrounding land a rich vegetation thrived, the decay of which gave rise to vast beds of carbonaceous matter mixed with a certain amount of fine sediment. Such were, in a general way, the conditions under which originated the beds of coal which make the period so important in its influence upon modern conditions.

FORMATION OF COAL SEAMS.—As to the precise manner in which individual coal beds were formed there is still much difference of opinion. Some maintain that the vegetable matter of a seam or vein of coal grew and decayed on the spot, and in support of this it is pointed out that underneath each seam there is a layer, usually of about the same thickness as the coal itself, of fine clay. This **UNDERCLAY**, as it is called, differs from the bulk of the sediment in containing very little soluble salts of potash and soda, for the reason, it is stated, that these materials were removed from the soil by the plants which were rooted in it. It is therefore regarded as the actual soil on which the Coal-measure vegetation grew. The absence of the above salts makes the clay extremely difficult to fuse, a property which renders it of great commercial importance for the manufacture of fire bricks used in lining the insides of furnaces and for other purposes of a similar kind. The "growth-in-place" theory is also supported by the fact that the fireclay is traversed by innumerable rootlets, and occasionally a Coal-measure tree has been dis-



The more important areas where coal seams were laid down are shown by dots. (After de Laparent.)

covered standing vertically in the clay in the position of growth, and passing up into the overlying seam.

It must be remembered, however, that although fireclay is very commonly found underneath coal beds, it is not universal, and in many cases the latter can be proved to be made up of vegetable matter drifted from a neighbouring land area, being made up of chips and fragments of woody material which had been collected together, somewhat as corks and other floating refuse are gathered into little heaps and left along high-tide marks around our coasts. In other cases the coals contain broken fragments of fish remains, which had obviously been swept together by currents. Both conditions seem to have been adequate for the accumulation of a huge mass of vegetable matter, which was subsequently protected from complete decay either by being covered with water or by sediment of a different kind.

The thickness of a seam may vary from a fraction of an inch to several feet, while exceptionally, as in the case of the Xaveri seam in Upper Silesia, it may reach as much as 17 yd. Most of the worked seams range between 6 ft. and 1 ft., those of less thickness being usually unworkable. In any given coalfield the proportion which the aggregate thickness of coal beds bears to the total thickness of other sediments, usually known as "measures", is small, (probably less than one part in thirty as a rule), so that the conditions for the formation of coal alternated with other conditions when ordinary deposits of muds and sands were laid down. In certain districts these sometimes contain fossil shells, which are generally regarded as having belonged to animals which inhabited fresh water; fish remains are also, occasionally found, but in other districts the measures contain bands rich in remains of marine organisms in addition to the freshwater types.

It would appear, therefore, that although the majority of coal measures and coals were deposited or grew in fresh water, there were in some areas occasional incursions of the sea, carrying with it its own organisms. The fact that coal seams alternate with measures a large number of times in a given coalfield shows clearly that the area must have been undergoing slight oscillations, now rising slowly, now sinking gradually, and at other times remaining stationary for long intervals. As, however, the measures from top to bottom seem to have been laid down under much the same shallow-water conditions, it is probable that on an average the area was slowly sinking, and that the silting-up with sediment just kept pace with the subsidence.

FORMATION OF COAL.—We have next to consider the changes which the accumulated soft vegetable matter underwent before it became true

coal. The first change was a partial decay under the influence of atmospheric and dissolved oxygen, resulting in a loss of water and carbon dioxide. As the beds became buried under later sediments the supply of oxygen was cut off, but chemical changes still went on in the tissues, so that an enrichment of the carbon relative to the hydrogen and the oxygen took place. Such changes would be facilitated by the pressure of the overlying sediments, which, however, could offer but little check to the escape of the gases from the decaying vegetation. Plants are made up of chemical compounds containing the elements carbon, hydrogen, and oxygen in varying proportions, as well as small quantities of nitrogen and sulphur. Small amounts of mineral substances are also always present. Decomposition and subsequent change sets free water and various gases—chiefly marsh gas (CH_4) and carbon dioxide (CO_2).

CHARACTERS OF COAL.—Coal as we find it is a hard, brittle, black, shining substance, composed chiefly of the above elements, as well as some mineral matter which remains as ash when the coal is burnt. It differs essentially from unchanged vegetable matter in the much higher proportion which the carbon bears to the hydrogen. This proportion varies indeed in different coals, and is of importance in determining the uses to which the coal can be applied.

KINDS OF COAL.—Three kinds are usually distinguished: (1) soft coal, house coal, or bituminous coal, in which the proportion of C to H is relatively small; (2) steam coal, with a higher proportion; and (3) hard coal, or anthracite, with the highest proportion of all; in fact, the purest kinds of anthracite contain little else than carbon. The difference between various kinds of coal, peat, and ordinary wood may be seen from the following table of analyses, taken from Chamberlin and Salisbury's *Geology*, Vol. II, p. 570, where, however, the proportion of carbon to hydrogen is not worked out.

| | Carbon. | Hydrogen. | Oxygen. | Nitrogen. | Proportion of C to H. |
|-----------------|---------|-----------|---------|-----------|--------------------------|
| Wood... .. | 49.66 | 6.21 | 43.03 | 1.10 | $\frac{8}{1}$ |
| Peat | 59.5 | 5.5 | 33.0 | 2.0 | $\frac{10.8}{1}$ |
| Brown Coal ... | 68.7 | 5.5 | 25.0 | .8 | $\frac{12.5}{1}$ |
| Bituminous Coal | 81.2 | 5.5 | 12.5 | .8 | $\frac{14.8}{1}$ |
| Anthracite ... | 95.0 | 2.5 | 2.5 | .0 | $\frac{38}{1}$ |

EFFECTS OF PRESSURE.—In addition to ordinary changes due to decomposition, the coal beds have in most cases been subjected to great pressures by the accumulation of an enormous thickness of sediment above them; some again have been carried down to considerable depths in the earth's crust by slow subsidence, and have thus been brought under the influence of higher temperatures than are found at the surface; while, as will be seen in the sequel, many of the areas where coal was formed have been visited by violent earth movements, whereby the seams, as well as the measures enclosing them, have been folded, twisted, and broken. All these accidents have contributed to bring about the conversion of the soft vegetable matter into the condition of hard, bright coal. •

USES OF COAL.—The bituminous varieties are used mainly for the manufacture of gas and coke, and for household purposes. From the industrial point of view they are the most important of all, as from their distillation for the manufacture of gas is obtained the crude product known as coal tar, from which innumerable organic compounds are prepared, many of them of the first importance in certain industries. The use of soft coal for household purposes is attended with a serious disadvantage from the difficulty of completely burning it; the incompletely burnt material escapes into the air as smoke, and gives rise in large towns to serious visitations of fog. For this reason also it cannot well be applied to the same special purpose as the second kind—steam coal. This burns with a clear flame, and gives off but little smoke, while its heating power is very high; these two qualities render it especially suitable for consumption in warships, and, indeed, this kind is used by nearly all the navies of the world.

Anthracite burns with an intense red glow and with very little flame. It is, however, difficult to light, and is generally more troublesome, as the use of anthracite for household purposes usually requires the construction of special stoves; but there is no doubt that if its use became general a great deal of the inconvenience caused by the smoke and dust of large towns would be avoided. Fresh means are continually being devised for utilizing it, and it is possible that in the immediate future it will to a large extent replace other kinds, not only for household purposes, but also for the generation of power. An ingenious attempt has already been made in the latter direction. Steam and air are passed over a glowing anthracite fire, whereby chemical change sets in with the formation of hydrogen and carbon monoxide. These gases are then mixed with air, and led into a combustion chamber similar to that of an ordinary gas or oil engine, where they are exploded in the usual way.

Various processes are now in use for compressing what is known as "small coal" into briquettes, which are used for household purposes, but the industry is better patronized on the Continent than in Britain.

DISTRIBUTION OF COAL.—Although conditions favourable to the accumulation of coal prevailed over enormous areas during the later part of the Carboniferous period they were by no means universal. There were other regions much greater in extent where marine conditions predominated and calcareous deposits were laid down, while such coal seams as were developed in those areas belong to an earlier stage. The coal-forming phase (see plate) extended across northern and central Europe, and reappeared in the eastern parts of North America, emphasizing once more the essential unity of the history of these two portions of the earth's surface now separated by the wide Atlantic basin. In these regions the sequence of events was everywhere the same—an initial shallow-water stage, followed by a marine stage, which gave way to the peculiar final shallow-water stage when the coal seams were formed. In the other region the formation of coal attended the initial shallow-water stage, which was followed by gradual subsidence and the development of marine deposits nearly free from terrestrial vegetable matter. This marine phase prevailed over a great part of Russia and other areas of southern and eastern Asia on the one hand, and over North America, west of the Mississippi, including the Rocky Mountains, on the other. Limestones of this stage have been observed also on certain islands in the Malay Archipelago, and in Spitzbergen, Nova Zembla, and others within the Arctic Circle.

Another region, which may be distinguished as the Mediterranean Region, shared both conditions, and the sediments are consequently of mixed character, resembling those of central Europe on the one hand and those of Russia on the other. It comprises the Carboniferous deposits of Spain, the south of France, and the Alps, and probably those of the Balkans, while those of North Africa may probably be included in the same region.

Calcareous and coal-bearing strata somewhat similar to those of central Europe are known from certain parts of South America, Australia, and Tasmania, showing how extraordinarily widespread was this peculiar phase of deposition.

CLIMATIC CONDITIONS DURING THE CARBONIFEROUS PERIOD.—It is the general opinion that in the Northern Hemisphere the climate during the period was warmer than the present; the Lower Carboniferous seas show abundant evidence that corals and other organisms which now

inhabit warmer regions lived freely in them; unless, therefore, these organisms have altered in their habits the above conclusion is justified. On the other hand, there is evidence that at this period or slightly later wide areas in the Southern Hemisphere were under the influence of glacial conditions, and therefore cooler than they are at the present day; but whether the average temperature over the globe was higher or lower than at present cannot as yet be discovered. The great development of plant life during the formation of the Coal Measures points to a mild, moist climate of medium temperature, if one can argue from analogy with the present day; for too low a temperature would check plant life, while too high a temperature would cause such rapid decay that the preservation of the large quantities of vegetable matter necessary to form the beds of coal would be almost impossible. The character of the vegetation fairly justifies the conclusion that the atmosphere, at any rate in those regions where coal was forming, was a moist one. It is difficult to imagine that kind of vegetation flourishing to so great an extent under any other conditions.

CHAPTER VIII

THIRD CONTINENTAL PERIOD—PERMIAN AND TRIAS

Towards the close of the Carboniferous period there was a general rise of the land in the Northern Hemisphere, which culminated in very powerful earth movements. Ranges of mountains came into existence where previously there had been sea since very early times, and the whole aspect of that part of the earth's surface underwent a radical change. The more important features of the movement and its influence on the succeeding deposits will be treated of below.

MOUNTAIN-BUILDING.—In the Northern Hemisphere these deposits show evidence of having been accumulated under peculiar conditions, which were more or less directly connected with the earth movements, but in more southern latitudes, where the disturbances were not felt, the sea maintained its sway throughout, and sediments of ordinary marine types were laid down. The elevation which commenced at the close of Carboniferous times reached its greatest intensity in the Northern Hemisphere, more especially in Europe and western Asia, where it gave rise to two sets of mountain ranges trending almost at right angles. The

central Asiatic region appears also to have suffered elevation and folding at about this time. In Europe the most important set had a general east-and-west direction, and was produced by intense folding and squeezing of the rocks, accompanied by powerful fractures. The individual folds were of the unsymmetrical type, the steep limb or septum being frequently vertical or even overturned (overfolds), and always facing away from the centre of the range—a sure indication that the forces which elevated the mountains acted outwards from the centre as well as upwards. The violent pressures often developed the structure known as slaty cleavage in the softer rocks, whereby the original stratification became almost obliterated and replaced by the cleavage-planes.

Some volcanic activity accompanied or followed the movement, the material in many cases reaching the surface in the form of flows of lava or showers of ashes, but more frequently large masses of molten rock were forced into the strata at a depth, setting up great changes in the rocks in their neighbourhood, and often giving rise to valuable mineral deposits. During and after the uplift of the mountains, denudation was actively at work in levelling them off, and in the course of a long period of time the high ranges of mountains were worn down to an undulating surface not far above the level of the sea, thus exposing to view the rocks that were at one time hidden at great depths, and enabling one at the present day to glean some idea of what took place in the heart of the mountains during that far-off period.

A brief account of the course of this important post-Carboniferous elevation may be of interest (see plate). The northern margin of the folded mountain chains extended from the south of Ireland through the coalfield of South Wales, and thence crossing the Bristol coalfield passed to the north of the Mendips. Its further course in the south of England cannot be followed at the surface, as the old mountains have there been buried under later sediments, but indirect evidence of its existence underneath has been obtained, and its position can be determined approximately.

This is confirmed when the region beyond the Channel is examined. The Belgian coalfields have been affected by intense movements of a type similar to those in the south of England and Ireland, but the rocks have been folded and shattered to a much greater extent. The northern limit can be followed in a direction a little south of east from Calais to Valenciennes; the range then turns slightly northwards along the border of the Ardennes, past Namur and Liège, towards the Düsseldorf coalfield; beyond this it disappears under the recent deposits of the north German plain. Leaving the margin of the chain and proceeding

towards its interior, increased folding and faulting of the strata become apparent, affording some indication of the more complex conditions in the heart of the mountains.

Nowhere can this be seen more clearly than in the west of England, where, in passing from the South Wales or Bristol coalfields towards Devonshire, the rocks become increasingly more contorted and shattered, while older beds appear at the surface which were once buried under a great thickness of rocks. The folds are unsymmetrical and usually inverted, while the faults are overthrusts along which older strata have been pushed over from the south on to younger strata on the north. In Devon and Cornwall the first igneous rocks are met with in the great granite masses of Dartmoor, Bodmin, and others; at some late period of the movement these were forced in a molten state among the deeply-buried rocks, and have been brought to view by the subsequent removal by denudation of the enormous cover of overlying strata.

THERMAL METAMORPHISM.—Close to the margin of the granite the physical characters of the sediments have been entirely changed by the intense heat of the molten masses forced among them, and it is sometimes extremely difficult to determine their original state. What were previously soft muds, shales, or limestones have been thoroughly recrystallized, and a host of new minerals have arisen by a chemical recombination of the elements of the rocks under the influence of the prolonged and intense heating. In addition to this, minerals of great commercial importance at the present day owe their origin to the same series of events. The intensely heated vapours driven out from the molten masses passed up through the strata, and escaped along fissures which were formed in great abundance in and around the granite areas; those gases brought up in one form or other the elements of the tin and copper minerals, which were ultimately deposited on the walls of the fissures, where they crystallized. It is probable that much of the vapours reached the surface and escaped into the air, as is observed frequently in modern volcanic regions. The minerals which were formed in this way deep in the earth have been laid bare by the same denuding forces as exposed the consolidated granite masses, and now form one of the most important sources of tin and copper in the world.

To the south of the rich mining districts of Devon and Cornwall, which lie principally in the Devonian and perhaps the Silurian rocks, older strata form the surface, which have been pushed up from the south along important overthrust faults, while still farther south are the old crystalline gneisses and schists, probably of pre-Cambrian age, fringing the coast and

appearing again in some of the neighbouring islands—on one of which the Eddystone lighthouse has been built. These old crystalline rocks of Cornwall are only the forerunners of the much larger masses of them which appear across the Channel in Brittany, where the centre of the chain probably lay; the site of the present English Channel was at that period occupied by mountains.

Brittany is floored by large areas of pre-Cambrian rocks, among which appear narrow belts of Cambrian and Silurian strata, which are merely the ends of deep troughs of the sedimentary series pinched in among the crystalline masses. About the middle of the Bay of Biscay the southern visible limit of the chain is reached; the region to the south is covered over with younger sediments, and no evidence has been obtained of the continuation of the uplift in that direction. This immense range, of which only the worn-down stumps are now visible, must therefore have extended nearly 400 miles from north to south. The southern termination can be traced in a south-easterly direction from the Bay of Biscay along the north of the Gironde valley to the upland region of the Auvergne, where it takes an abrupt turn to the north-east, and ranges almost parallel to the northern margin of the Alps as far as Bohemia, beyond which it becomes concealed again under later sediments. It does not appear to have crossed the plains of Poland and Russia, as wherever the Palæozoic rocks are exposed in that direction they lie undisturbed and nearly horizontal.

The chain presents the same characteristics at whatever part it is crossed. Coalfields or Carboniferous rocks are found nearly everywhere along its northern margin, and the coal seams and the strata which include them are highly disturbed all the way from England to the Rhine; in the Belgian coalfields the same bed of coal which had been twisted into a zig-zag fold was pierced three times in a single vertical shaft. Everywhere the Carboniferous rocks are followed towards the interior by Devonian rocks, likewise intensely disturbed, and not infrequently thrust bodily over the younger strata—for in the Pas de Calais the Coal Measures were worked underneath the Devonian rocks.

The latter strata form the greater part of Devon and Cornwall, the Ardennes, and the Eifel, while still nearer the centre of the chain are the older sedimentary series alternating with crystalline and volcanic rocks; these are now much broken up both by denudation and by the extensive subsidence along normal faults which followed the folding movement; so that only the stumps remain of the once-continuous mountain core. The hard nature of the rocks of which these stumps are composed has enabled

them to resist the ravages of denudation better than the strata by which they are surrounded, and they stand up in the picturesque hills and mountains of the Harz, Thuringer Wald, the Odenwald, Schwarzwald, and Vosges on the Upper Rhine; they also cover large areas of Bohemia in the east and the Central Plateau of France in the west. These isolated masses of Palæozoic and pre-Cambrian rocks projecting out of younger sediments form, as it were, the skeleton from which the old post-Carboniferous mountains can be reconstructed in imagination.

On the east of the vast plains of Russia are the Ural Mountains, a narrow chain pursuing an almost north-and-south direction, which was also elevated at the close of the Carboniferous period. This, as will be remembered, is the dominant direction of the other mountain ranges of that period, which are represented in England by the Pennine Chain and the Malvern range. The smaller Timan range, lying to the west of the Urals, is a parallel chain of the same age. The Urals, however, are more comparable in the overthrusting and overfolding along their western margin with the east-and-west type than with the Pennine chain, where these structures are absent or only feebly developed; they indicate that the range has been pushed from the east towards the Russian plain. The former extent of the range has been greatly reduced by subsequent denudation and by a covering of later sediments. The central Asiatic uplift was somewhat in the form of a horseshoe surrounding the higher regions of the present Lena and Yenissei rivers; the chain was everywhere pushed towards the interior of the horseshoe. It is probable that a small range occupied the region of north-west Spain at this period, but whether it formed a part of the larger elevation cannot be discovered, as, if a connection existed, the evidence of it is hidden under the waters of the Atlantic.

The movement was not confined to Eurasia, for in North America there is evidence of an important mountain-building movement at the close of the Carboniferous period. The regions chiefly affected had been more or less submerged since the first continental period, and a great thickness of sediments had therefore accumulated. These were elevated into two mountain chains; the first ranges in a direction from north-east to south-west; the strata were highly folded and faulted by forces acting towards the interior of the present continent. The western margin of the chain extended from the north of Nova Scotia parallel to the St. Lawrence, and along the western side of the Appalachians and the Alleghanies. The rocks to the east of the St. Lawrence are highly folded, while those on the west are undisturbed. The continuation of the chain to the south is concealed under younger strata, while on the north it runs under the sea

of Greenland. Its former extension to the east is likewise concealed by the ocean, but from the striking parallelism of the present coast line with the direction of the folds there is little room for doubt that this feature was to a certain extent determined by the events at the end of Carboniferous times. The second uplift affected the Rocky Mountains, but these were uplifted also at a later stage.

CONSEQUENCES OF MOUNTAIN-BUILDING PHASE.—Having traced the main lines of this great mountain-making movement, it will be necessary to consider its more immediate consequences both in relation to previously existing strata as well as to those which were formed later during the succeeding quiescent stage. One of the direct results was the hardening and stiffening of the Palæozoic rocks, which has enabled them better to resist the denuding forces of later times, for it is found that where those strata have been affected by the movement they stand up at the present day as prominent features on the earth's surface, while in those regions, such as the borders of the Baltic, where the movement did not penetrate they still remain in a loose incoherent condition, and form monotonous country of low relief. It may be stated in general that the more rugged parts of the earth's crust are those which have been affected by violent earth movements subsequently to the formation of their rocks.

The effects of the elevation on the Coal Measures are of great importance from a commercial point of view. The continuous areas of coal-bearing strata were uplifted above the level of the sea and thrown into ridges and troughs; a large amount of coal must have been swept off the ridges by the succeeding denudation, but the troughs were protected from its influence. Had it not been for the elevation, however, the Coal Measures would have remained under water, and their rich stores would have been withheld perhaps for ever.

Just as the eastern coast line of North America was predetermined at this stage, so were the main features of central Europe, while the present boundary between Europe and Asia which runs along the Ural range is clearly traceable to the same series of events. It is probable also that the drainage system of central Europe owes not a little to the post-Carboniferous uplift, for it is a striking fact that the principal water parting coincides in a general way with the centre of the great chain; but the details of that drainage are the result of many subsequent accidents which befell the same region. If, as is likely, a drainage system was originated in the west of England and Wales by the east-and-west elevation, nearly all traces of it have been obliterated.

The connection between lines of drainage and the north-and-south

elevation is more obvious both in Europe and North America. The Penine chain persists to this day as the principal water parting of the north of England, though, as has been pointed out, there have been many changes in the courses of individual streams; again, in the Urals the tributaries of the Oby on the east, and those of the Ural, Volga, and Petchora on the west, divide along the centre of the chain, while in North America the Alleghanies and Appalachians separate the coast drainage from that of the Mississippi feeders, but subsequent events in the latter region have modified the drainage system considerably and thereby masked its original simplicity.

NEW RED SANDSTONE.—The deposits of the Third Continental Period are embraced within the Permian and Triassic systems, and are sometimes spoken of collectively as the New Red Sandstone to distinguish them from the red strata immediately preceding those of the Carboniferous period.

DESERT CONDITIONS.—The emergence of land from beneath the sea was not confined to the mountain country embraced by the folding movements but was a general incident, especially in the Northern Hemisphere. An exceedingly large area of new land was thereby created, which was traversed or bordered by high mountains. These circumstances would in themselves be eminently favourable for the setting up of desert conditions, but there is some evidence that in addition a fairly high temperature prevailed, due in part to the distribution of land and sea at the time, and probably to other conditions which are discussed below.

WARM CLIMATE.—As was pointed out by Lyell, a large mass of land in low latitudes (*i.e.* approaching the Equator) ensures a warm climate, for the reason that a land area is rapidly heated and imparts some of its heat to the air in its neighbourhood, which rises and moves in the higher regions of the atmosphere towards the poles. Those areas serve therefore the purpose of a "hot-air apparatus" for the colder regions. On the other hand, water absorbs heat slowly, but also it parts with it tardily, so that the presence of a great body of water prevents extremes of heat and cold.

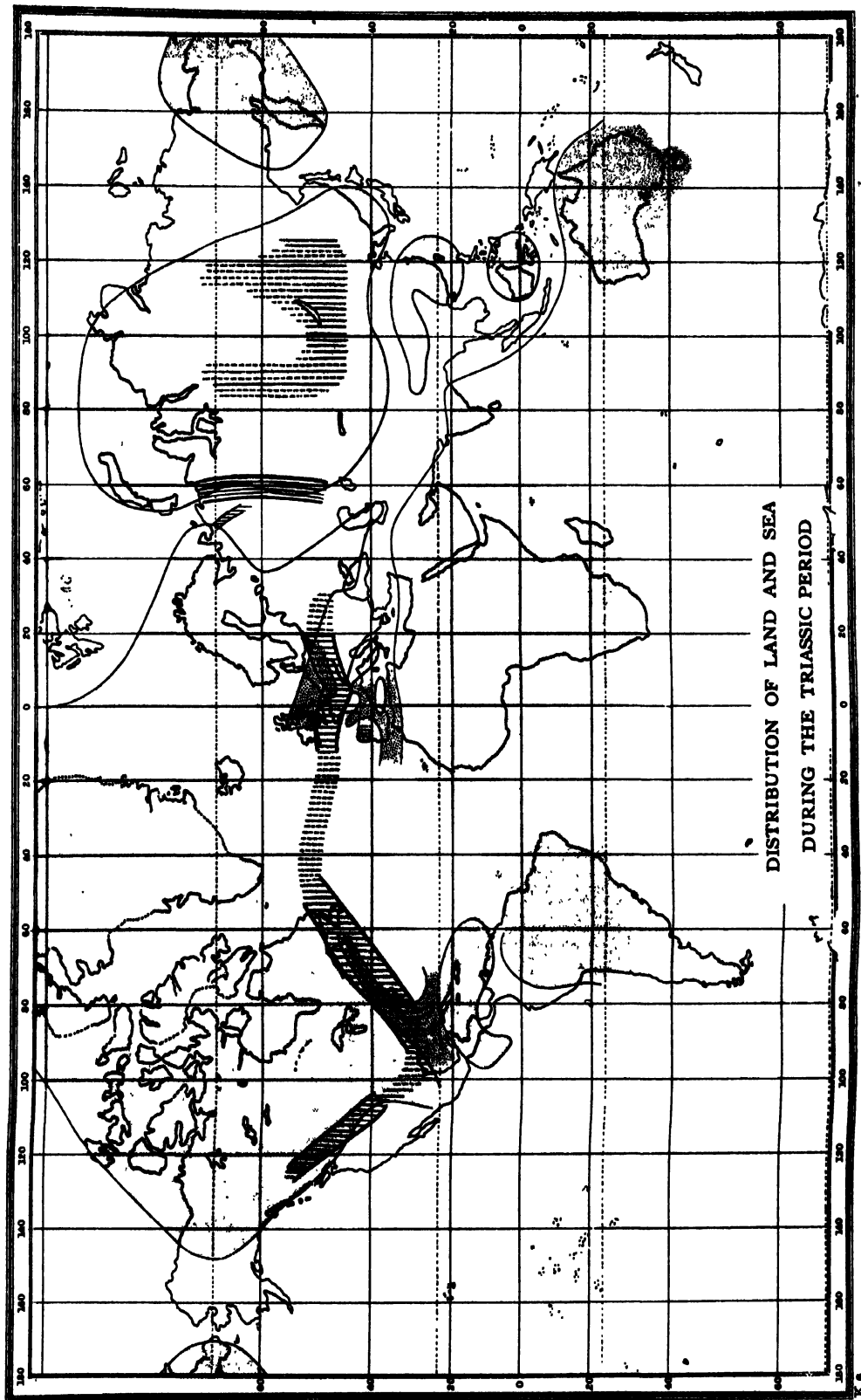
Applying these considerations to the period in question there is evidence that the north polar region remained under the sea throughout, while the great land mass extended over the greater part of the Northern Hemisphere from moderate to low latitudes, and therefore without assuming that the general temperature of the earth was higher at that period than to-day the fairly warm and arid conditions necessary for the formation of deserts might be expected.

NATURE OF DEPOSITS IN NORTH-WEST EUROPE.—The deposits

which bear the stamp of continental and desert conditions are found extensively in central England, and are continued under younger strata to the centre of Germany, where they wrap round the remnants of the post-Carboniferous chain and rest on the upturned and eroded edges of the older rocks, showing that a long period of denudation had preceded their deposition (see plate). Their mode of occurrence and physical characters throw considerable light on their origin and on the conditions which prevailed during their formation. They consist, in the main, of bright red sands and clays commonly called marls, with, especially in the earlier stages, frequent beds of well-rounded pebbles, and irregular patches of breccias made up of angular fragments. The floor on which they were laid down was often highly uneven, for they are not infrequently found banked up against the older rocks in such a way as to suggest the existence of cliffs projecting out of shallow water or the surface of a desert. The breccias are such as would be washed down from the high ground by torrential rains, while the pebbles imply transport by rivers for a considerable distance. The finer deposits are to a larger extent "millet-seed" sands, which are known to be characteristic of desert areas.

The composition of the pebbles and the minerals associated with the grains of sand suggest that in England they were derived from a southerly direction, where, as will be remembered, lay the post-Carboniferous mountain chains. In some districts, especially the Charnwood Forest of England, the pre-Cambrian rocks underlying the red sands exhibit as typically wind-eroded and polished surfaces as any modern desert. But while many of the coarser deposits may have been formed on a land surface or carried off such a surface into the water areas, the finer deposits were probably accumulated in inland sheets of water like the modern Caspian Sea, or in constricted arms of the sea where evaporation was rapid. On some of the muds, sun cracks formed by drying when the water level was low, pittings produced by heavy rain, and the tracks of animals have been preserved, all of which afford a clear insight into the conditions under which such strata originated. These indications, as well as the prevailing red colour of the deposits, support the conclusions drawn above as to the climatic conditions of the period.

FOSSILS.—Remains of animal life are scarce, but when, as occasionally happens, beds of limestone or dolomite are found, they contain marine shells, which are usually stunted and belong to but few species, implying that the organisms were struggling against adverse conditions, probably excessive salinity of the water. The poverty of species suggests that many of the forms succumbed, or, where possible, migrated into other



The end of the Third Continental Period. Areas where deposits of a lagoon or continental type were laid down are shown by dots.
(After de Lapparent.) The positions of the Post-Carboniferous mountain ranges are indicated by vertical bars, broken where very uncertain.

THIRD CONTINENTAL PERIOD

areas where the conditions were more favourable. It is usually noticed that in Europe the limestone beds thicken southwards and eastwards, and remains of life become more abundant, showing an approach to the open-sea conditions which prevailed in that direction.

ECONOMIC PRODUCTS.—Of great importance commercially is the existence in these red rocks of thick deposits of inorganic salts, mainly chlorides and sulphates of calcium, magnesium, potassium, and sodium, all of which occur in small quantities in sea water; the more insoluble salts, as sulphate of calcium, are of frequent occurrence in the New Red Sandstone rocks, but the soluble salts are rarer. There is little doubt that these deposits were formed by the long-continued and more or less complete evaporation of an inland sea under the influence of a warm and dry climate, when the various salts crystallized out as the water

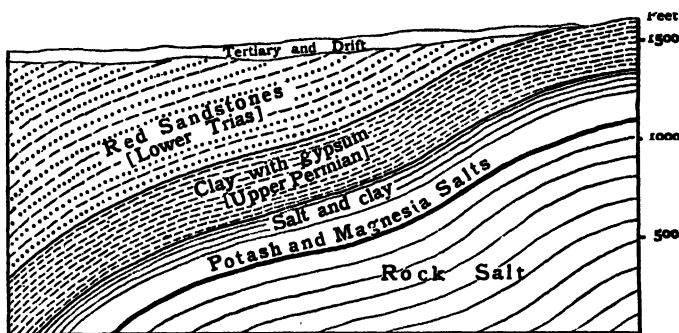


Fig. 36.—Diagrammatic Section through the Stassfurt Salt Beds

became saturated. After deposition they were covered over by fresh muddy sediment brought down from the adjoining land, and were thus protected from subsequent solution by percolating waters.

The famous salt deposits of Stassfurt, in Germany, which are interbedded in Permian strata, are known all the world over. The rock-salt bed is about 1200 ft. thick, and is followed by about 150 ft. of the more soluble potassium and magnesium salts known as Abraum salts (fig. 36). This enormously thick salt bed is believed to extend under a large area of central Germany, probably reaching as far as Berlin; in many cases its occurrence is only indicated at the surface by springs of strong brine.

In Britain deposits of inorganic salts are also found, but in strata of later date (Upper Trias); only the less soluble products of sea water, such as sulphate of calcium (gypsum) and chloride of sodium (rock salt), occur. The absence of the more soluble constituents points to a less complete evaporation in those regions. In Cheshire, where most of the

rock-salt deposits occur, the beds are sometimes mined underground like coal, but more usually water is introduced, and the salt is pumped up in the form of brine. Around Nantwich and Stoke the removal of the salt in solution has caused the subsidence of large tracts of the surface on which sheets of water collect, and it has been suggested that some of the Cheshire lakes or meres are due to subsidence consequent upon the removal of soluble salts by percolating underground waters.

Conditions of a like nature prevailed in North America on the eastern slopes of the Alleghanies, and in the eastern and central parts of the



Fig. 37.—Section of Glacial Conglomerate of Triassic Age near Prieska, South Africa (Schwarz)

Rocky Mountains. The strata are there associated with rich coal beds, and also with considerable outpouring of lavas.

PERMO-CARBONIFEROUS.— It has been observed that in the Carboniferous period parts of Europe and North America offered different types of deposits from those of the rest of the globe, a difference which was maintained in the succeeding period, for in eastern Europe, parts of Asia, India, Australia, and certain regions within the Arctic Circle, the marine Carboniferous sediments were followed without interruption by other strata mainly marine, which correspond to a time intermediate between the European Permian and Carboniferous, to which the term Permo-Carboniferous has been applied. The deposits bridge over the gap between the two periods in central Europe, where marine sediments

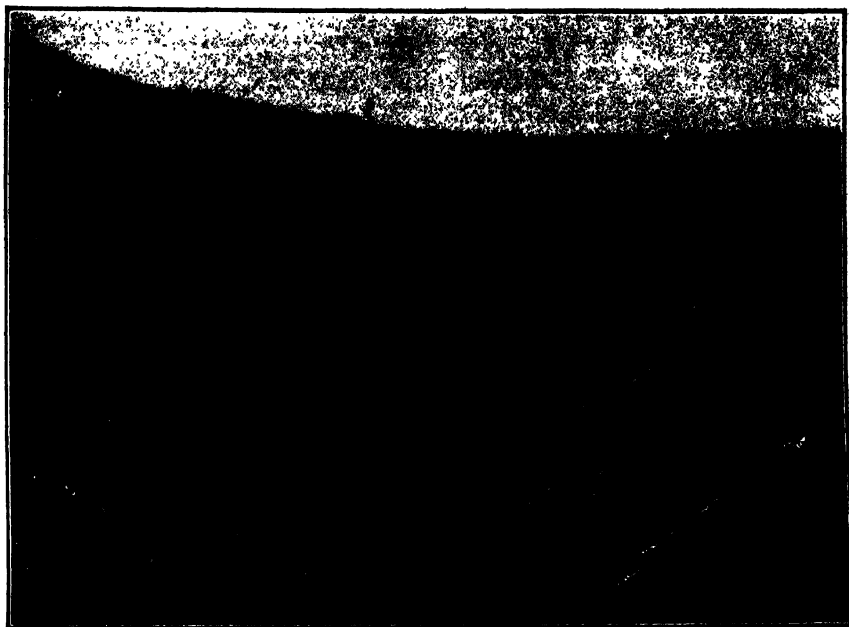


Fig. 38.—Glaciated Quartzite beneath the Triassic Glacial Conglomerate near Prieska, South Africa. The rock surface shows glacial striae (Schwarz)

are absent on account of the earth movements and continental conditions which prevailed there.

GLACIAL DEPOSITS.—One of the features of that period was the striking similarity of conditions throughout the Southern Hemisphere, which extended both to the marine and to the freshwater sediments. The most interesting deposits are those which show the undoubted existence of glacial conditions at some part of the Permo-Carboniferous period. In India, true boulder clays, containing typical scratched and smoothed boulders (Talchir Beds), lie at the base of the marine and freshwater series. Again, in South Africa, the Dwyka conglomerate is of precisely similar character and occupies a corresponding position (fig. 37). Further, it can be seen in many places to rest on a platform of rock which has been thoroughly grooved and polished by the movement of ice over it (fig. 38).

Similar conditions prevailed in southern Australia, where the glacial beds also lie at the base of the Permo-Carboniferous rocks; while boulder beds, probably formed in the same manner and at about the same period, have been discovered in the Argentine Republic and in the Falkland Islands. Thus, so far as any land exists at the present day in the Southern Hemisphere, to allow one to form an opinion, it would seem that glacial conditions obtained over an extensive area.

In northern India the boulder beds are followed by a marine series

which persisted far into the Secondary period; but over a great part of Asia, as well as South Africa, South Australia, and the Falkland Islands, land conditions seem to have prevailed, since, as a rule, the boulder beds are followed by coal-bearing strata carrying the remains of land plants.

PERMO-CARBONIFEROUS PLANTS.—A remarkable uniformity is observed between the Permo-Carboniferous plant life of the Southern Hemisphere. In central India, Victoria (South Australia), South Africa, and in some parts of South America, there has been found a peculiar flora known as the *Glossopteris*-flora, characterized by certain ferns, of which the above-named genus and its immediate allies are the most important. The enormously wide distribution of these ferns over that hemisphere suggests the existence of an extensive and connected land area, on which they lived and were distributed. It is a remarkable fact that the deposits formed in those regions of central Asia visited by the post-Carboniferous uplift resemble closely those of the Indian continent, and also contain the *Glossopteris*-flora. As will be shown below, a considerable tract of sea separated the two regions at that period, which might be expected to interfere seriously with the distribution of the ferns.

SOUTHERN LAND.—It has been suggested by Professor Suess that the southern continents mentioned above, and probably also South America, were joined at that period to form one vast continental area, to which he has given the name Gondwana-land, after a province of central India. He supposes that the breaking up of the continent took place by gigantic faulting, and that it was an event of comparatively recent date. Whether such a sweeping generalization is justified by the amount of evidence hitherto obtained is open to doubt, but such an hypothesis certainly accounts for what is a remarkable fact, viz. the close similarity, not only during that period but in much later times, between what are now the continents of India, South Africa, South America, and Australia.

It would be interesting to know how much land existed around the South Pole, and whether there was any connection between that land and the more northern tracts. The South Polar regions at the present day seem to resemble geologically the Australian continent, and may at one time have been connected with it. According to Lyell, a large mass of land in high latitudes, especially if it extended up to the pole, would give rise to a cold climate over that hemisphere, and it is possible that the phase of extreme cold which gave rise to a glacial period in the Southern Hemisphere was due to some such geographical conditions, while the warm and arid climate over the Northern Hemisphere at the same time was due to the opposite set of conditions.

GLACIAL THEORY OF CHAMBERLIN AND SALISBURY.—The American geologists Chamberlin and Salisbury have lately developed a theory of glaciation which pertains not only to the period under consideration but to all others. It is based on the influence which the constituents of the atmosphere exert in protecting the surface of the earth from loss of heat by radiation into space. The greatest effect is assigned to the carbon dioxide and the water vapour, which are known to have considerable power of absorbing heat. If, therefore, from any cause these two constituents suffer serious diminution, a general fall of temperature of the earth's surface must ensue. The localization of cold conditions is assigned, with some reserve, to special geographical and meteorological considerations. An attempt will be made to outline their hypothesis as applied to the Permo-Carboniferous glacial period. The complete theory involves many subsidiary effects, and a full statement would occupy too much space.

The Carboniferous period was remarkable for the development of enormous masses of limestone which were of general distribution. Their formation made serious demands upon the carbon dioxide of the atmosphere as well as upon that dissolved in the water. In addition, in the later stages a luxuriant vegetation thrived which made further inroads upon the supply of carbon dioxide. It is considered, therefore, that that constituent was almost removed from the atmosphere and from the water towards the close of the period. Great earth movements then followed; the ocean basins were deepened, and the average height of the land increased, especially along certain belts where the crumpling was most severe.

Those changes had several consequences upon the constituents of the atmosphere. In the first place, the withdrawal of the water from the land into the ocean basins diminished the surface of evaporation, and, in consequence, the amount of water vapour in the air. There is evidence that this was the case in the arid conditions which prevailed generally. In the second place, the greater surface of land exposed, and its increased altitude, favoured radiation of heat into space, especially as the lines of mountain ranges prevented the free circulation of the air in the lower regions of the atmosphere. The air was therefore forced to rise to great heights in the heated areas, and, after passing the barriers, descend into the cold regions. This involved great loss of heat to the atmosphere by radiation into space.

From those two causes a general lowering of temperature over the whole surface must have ensued. That, again, reacted on the amount

of carbon dioxide in the atmosphere, for water can absorb much more at a low temperature than at a high. Any cause that brought about a general fall of temperature would therefore enable more carbon dioxide to be absorbed by the sea waters, to the loss of the atmosphere. A third consequence of the upheaval affected that constituent directly. The land before the elevation must have been in the state of a peneplain over large areas, but the general raising of the surface above the sea-level gave new energy to the streams, and they proceeded to deepen their channels, and incidentally removed a large amount of loose soil which had accumulated on the peneplains. The carving out of river valleys and the removal of soil exposed large areas of fresh and unweathered rocks to the atmosphere.

In the process of weathering, carbon dioxide plays a prominent part, entering into combination with various bases, such as lime, magnesia, soda, potash, &c., forming compounds which are removed in solution. Hence fresh inroads would be made upon the already scanty supply of that gas.

These three effects—viz. the direct loss of heat by radiation consequent on the general upheaval of the land surface, the presence of barriers to free circulation in the lower regions of the atmosphere, and the secondary losses due to the depletion of the supply of water vapour and carbon dioxide, which rendered the blanketing power of the atmosphere less—are considered to have been sufficient to reduce the general temperature of the earth's surface sufficiently to allow a glacial regime to prevail over those regions where geographical conditions were favourable. The above-named authors suggest that during the Permo-Carboniferous period there may have been land connections between India, Australia, and New Zealand, and probably with Antarctica, which would seriously interfere with the oceanic circulation in the Southern Hemisphere. If the ocean currents are assumed to have been due to causes similar to those of the present day, then the warm Pacific currents which now pass into the Indian Ocean via the East-Indian Archipelago would be cut off and turned back into the Pacific, thus concentrating the heat there. Again, the cold currents from the South Polar region which now reach the Pacific via New Zealand would be turned into the Indian Ocean, or what then was of it. That region would therefore be likely to have a cold climate, suitable for the development of glaciers.

The older hypothesis, put forward some years ago by Croll in his *Climate and Time*, attributes this and all other glaciations to variation in the eccentricity of the earth, but this theory is too complicated to be stated here.

CHAPTER IX

THIRD MARINE PERIOD—JURASSIC AND CRETACEOUS

GENERAL SUBSIDENCE.—The continental period in the central European region was followed everywhere by one of gradual subsidence, when the sea once more crept slowly over the land. Long-continued denudation under a desert regime had already reduced the mountain areas to a low, rolling upland; the hollows had been partly filled-in by sediments, while marine erosion during the general subsidence completed the process of levelling, and thus an approximately plane surface had been prepared to receive the succeeding deposits.

NATURE OF DEPOSITS.—These are chiefly remarkable in containing a large quantity of calcareous matter in the form of limestones or calcareous sandstones and mudstones, which alternate with deposits of fine dark clay in many areas. On account of the very perfect planation which preceded the marine phase, it is probable that shallow water prevailed over extensive areas not only near shore lines but at a great distance away from them. The mechanical sediments derived from the land would form a relatively narrow fringe around the coasts, leaving the water beyond free from muddy material, and therefore suitable for the existence of calcareous organisms. Also, the floor of a shallow sea of this nature would be easily affected by earth movements of small amount, while coast-lines would be liable to considerable changes of position; it is therefore to be expected that variations in the character and distribution of the sediments would be numerous. Such is indeed found to be the case, yet in spite of this it may be said that throughout the first part of the period the sea was gradually gaining on the land, while towards the end a reverse process set in; this culminated in the powerful earth movements which brought the marine period to a close.

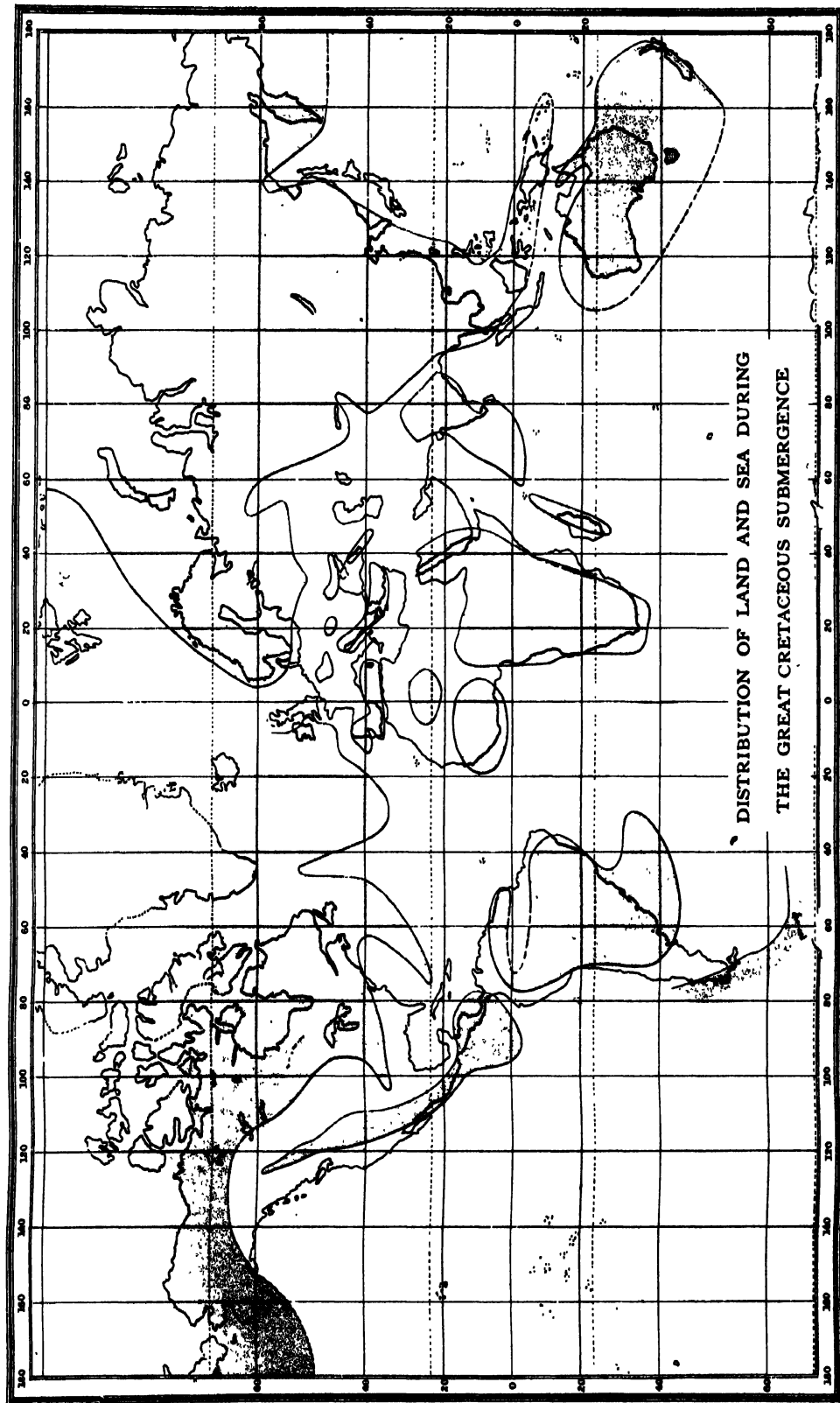
It will be convenient to consider the history of the earth's surface during this period with reference to certain existing features, which may be divided broadly into the following: (1) the Pacific border; (2) the Mediterranean region; (3) the Southern Continents; (4) the Atlantic borders; and (5) the Arctic regions.

THE PACIFIC BORDER.—There is reason to suppose that the Pacific Ocean has been in existence from a very early period, but its margins have from time to time undergone many important changes both in position and extent. During the greater part of the third marine period most

of the modern coast-line was under the sea, and only came into existence with the extensive earth movements which followed the marine phase. From the western coast of the two Americas round the Aleutian Islands, Japan, and New Zealand the series of marine Mesozoic sediments up to the Cretaceous is almost everywhere complete. The uniformity of conditions which prevailed over such an enormous area is one of the most remarkable facts in the geological history of the earth.

THE MEDITERRANEAN REGION.—This term is here used in a much wider sense than at the present day, for it includes a belt extending nearly parallel to the Equator from the Pacific border in eastern Asia till it meets that border again in central America. To avoid confusion with the modern feature it may be called the Central Sea of the Mesozoic period, or, more shortly, the **CENTRAL SEA**. From the interior of Asia Minor through the south of Europe and North Africa the Mesozoic deposits show evidence of having been laid down in an open sea, being mainly composed of massive beds of limestone built up from the remains of calcareous organisms. Again, in the Antilles, between North and South America, similar strata occur. It is probable also that much of the existing Himalayan region, in which limestones also play an important part, may be assigned to the same central ocean, though its connection with that extending across southern Europe has not yet been worked out. One may anticipate a little to point out that it was just where the Mesozoic Mediterranean or Central Sea existed that the mountain-forming movements succeeding the marine phase reached their maximum intensity, and therefore the site of that ancient ocean is largely occupied at the present day, not by an open sea, but by the highest mountain ranges on the surface of the earth.

THE SOUTHERN CONTINENTS.—What has been denominated the great land area of the Southern Hemisphere in Mesozoic times formed one of the most interesting and characteristic features of the period. We have seen that during the continental period glacial conditions prevailed over a great part of the southern regions, and we have also seen reason to suppose that a certain amount of land connection existed between the now-isolated continents of India, Australia, South Africa, and possibly also South America. That these regions remained above the sea in Triassic and Jurassic times is indicated by the absence of marine sediments of those ages, the deposits being mainly composed of sandstones and shales with remains of land plants, land animals, and fresh-water fishes. They lie on old crystalline rocks and on the eroded edges of folded and metamorphic Palæozoic strata, and are often associated



(Slightly modified from de Lapparent.)

with, or covered by, enormous sheets of lava (basalts), which in some cases form the surface of the country for hundreds of square miles.

INDIA.—On the Indian peninsula plant-bearing sandstones and shales, locally containing important coal seams and known as the GONDWANA GROUP, cover large areas of the high central regions. They succeed the boulder beds of the Permo-Carboniferous glacial epoch, and probably correspond to the Permian and early Jurassic, as is indicated by their plant remains. After their formation powerful faulting occurred, whereby large blocks of them were sunk in troughs of the Palæozoic and metamorphic rocks. To this fact they owe their preservation from denudation on the elevated plateau of central India. The later Gondwana beds were deposited in part during that movement, but mainly after the close of it, and their distribution therefore does not coincide with that of the lower beds.

As a result of the movement the Indian continent seems to have attained approximately its present form, for much of the region near the modern coast-line was depressed almost to sea-level, and the upper Gondwana beds were deposited on the depressed areas as well as on the higher plateau. Towards the end of the Gondwana period slow subsidence was in progress, for the uppermost deposits, though mainly plant-bearing, are interbedded with others containing marine fossils, which indicate an early Cretaceous age. At the commencement of the Cretaceous period, therefore, the sea covered a strip of the Indian continent which lay somewhat within the present coast-line, but it never penetrated to the interior, for the upper Gondwana deposits of the central plateau have in them no trace of marine organisms.

SOUTH AFRICA.—The history of South Africa during the same period bears a close resemblance to that of the Indian peninsula. The Karoo beds, with their remains of land plants and reptiles, correspond to the Gondwana series both in age and physical characters, and like them they succeed boulder beds of glacial origin (the Dwyka conglomerate). They are thousands of feet in thickness, and wherever they occur lie in horizontal sheets on the eroded edges of folded Palæozoic and older rocks. No trace of marine organisms has been discovered in them, but their plant remains indicate that they were deposited during the Permian and Triassic periods. Their upper part is frequently coal-bearing. As in India so in Africa the period of deposition was followed by extensive earth movement, whereby a strip of land near the present coast was depressed far below the level of the interior, and in places was covered by the sea, so that marine deposits were formed. These strongly resemble those of India referred to

above, and like them indicate an early Cretaceous age. Hence much of the dislocation to which South Africa owes its present form occurred towards the end of the Jurassic period, and the land connection which probably existed between South Africa and India would be severed by its operation.

SOUTH AMERICA.—Less is known about the interior of South America than about the two regions already described. Unfossiliferous sandstones overlying Carboniferous and older rocks form extensive tablelands on both sides of the Amazon Valley. They were deposited under terrestrial conditions, and are probably of Triassic or early Jurassic age. The terrestrial period was succeeded by extensive depression, for in Cretaceous times the sea gained access to a great part of the interior, though much of central and eastern South America probably remained above the sea throughout the Secondary period.

AUSTRALIA.—Similarly in the interior of Australia the metamorphic and gneissic rocks are followed by Palæozoic marine sediments, and all are folded. After the Carboniferous deposits there is a great gap in the succession, and no marine deposits are known of earlier date than the middle Jurassic. The Great Desert is covered by an extensive cover of sandstone of aerial formation, but as no fossils have ever been found therein its age is unknown. It is probable, however, that much of the Australian continent was a land area during the early part of the Secondary period, but the marginal portions gradually sank beneath the sea before its close.

THE ATLANTIC BORDER.—This term is used in a very wide sense, inasmuch as it includes much of north-west Europe north of the Central Sea, as well as eastern North America. The sediments are of the same general types throughout, indicating that the conditions under which they were deposited were in the main similar over the whole of this enormous area. They are well developed in England, and on account of the abundance of fossils which they contain early attracted attention. It was indeed from a study of these rocks that the great principle which underlies all the reasoning of stratigraphical geology was first discovered and clearly enunciated by William Smith in the early part of the nineteenth century. In England these rocks are comparatively undisturbed, and the order in which the different rock types follow one another can be readily made out. Furthermore, organic remains are abundant and in general well preserved. When the discovery was made that over wide areas certain kinds of fossils were restricted to certain kinds of rocks, and were not found in those which occurred above or below, the great principle that "strata are identifiable by their included organisms" followed

of necessity. England, therefore, has played an important part in contributing to our knowledge of the history of the period; this is shown, also, by the way in which the English names given to the various rock types have been adopted almost universally.

The gradual subsidence of north-west Europe at the close of the third continental period allowed the ocean to extend its margins, and marine sediments were deposited above those of a continental type. The initial shallow-water phase was a protracted one, and was followed by a comparatively deep-water phase, and this again by a final shallow-water phase of short duration, when the land rose somewhat abruptly, foreshadowing, as it were, the great earth movements at the close of the marine period.

Along the Atlantic border the marine shallow-water phase commenced in the early Jurassic and persisted into Cretaceous times; the deep-water phase is represented by the later Cretaceous rocks, while the final shallow-water phase occurred at the beginning of the Tertiary. As might be expected, however, marine conditions did not commence everywhere at the same time, and accordingly we find that the earliest Jurassic rocks are absent over wide areas. Further, the subsidence did not proceed uniformly but by oscillations, for after some of the early Jurassic strata had been deposited a marked submergence occurred affecting large tracts in north-west Europe. This continued with slight oscillations until nearly the close of the Jurassic; a reverse process then set in; the land rose and the ocean margin steadily receded; a climax was reached towards the end of the Jurassic and the early stage of the succeeding Cretaceous, when central and northern Europe was occupied by a series of lagoons and freshwater lakes in which the remains of land plants and freshwater shells were buried. Rapid evaporation caused the precipitation of gypsum and rock salt, and many of the sediments were coloured red by oxides of iron.

LAGOON CONDITIONS.—The conditions of these areas must therefore have been somewhat similar to those under which the Triassic sediments were deposited. One of the lagoons extended across the south-east of England towards Boulogne; another occupied a large part of Hanover in north Germany; while others are known to have existed in the west of France and in parts of Spain and Portugal. At the time of maximum emergence it is probable that eastern Europe was severed from western Europe. Coinciding with the emergence of land in Europe there was a submergence in northern Asia, and probably also in India and South Africa. It has been maintained that those events were interdependent, and to a certain extent this seems to have been the case.

GREAT SUBMERGENCE.—It is obvious that during the Mesozoic era the crust of the earth was by no means at rest, but undergoing constant small alterations in form which were reflected in changes of the land and sea margins, but the oscillations already described were only the forerunners of the enormous submergence which occurred towards the middle of the Cretaceous period. The greater part of eastern Europe was then covered by the sea, which extended across the southern half of Russia and central Asia to the Pacific coast, while the highlands of Archæan and Palæozoic rocks scattered about central Europe throughout Triassic and Jurassic times—remnants of the Armorican chain previously described—were for the most part submerged.

NATURE OF DEPOSITS.—The higher Cretaceous deposits bear the stamp of fairly deep-water conditions over most of the area, and the abundance of calcareous matter indicates that the sea was poorly supplied with sandy and muddy sediments, probably by reason of the low relief of the land that remained unsubmerged. In central and western Europe they take the form of a loose friable calcareous rock known as chalk. On the opposite side of the Atlantic the sea spread across central and western North America from the Gulf of Mexico through Texas and the western States, probably reaching northwards nearly as far as the Arctic Sea. As in Europe, many regions were submerged which had been above the level of the sea for a long interval.

EXTENSION OF CENTRAL SEA.—The Central Sea of the Mesozoic maintained its sway throughout the oscillations which affected more northerly regions, but during the Cretaceous submergence its margins were greatly extended over North Africa, Arabia, and Syria, and the whole of the region around the Aral and Caspian Seas, and even reached in that direction to the east side of the Indian peninsula. The deposits consist of hard, well-compacted limestones quite distinct from the soft friable chalk of central Europe, and point to accumulation in somewhat deeper waters.

A great part of South America was submerged, while Cretaceous sediments on the coasts of South Africa, India, and Australia indicate that the sea penetrated farther inland than it does at the present day, though the central portions of the three continents remained well above the waters throughout the phase of greatest submergence.

LAND AND SEA IN MIDDLE CRETACEOUS.—From the foregoing accounts it would appear that the relative proportion of land to sea during the middle Cretaceous must have been considerably less than at the present day, since part of all the southern continents as we now

know them have reappeared since that time, and only north-west Europe and northern and eastern Asia and the north-east portions of North America remained in the Northern Hemisphere (see plate). Vast land areas which were in existence at that period may, however, have been subsequently submerged.

LOST LANDS.—It is probable, for instance, that much of the North Atlantic was dry land—the remnants of Atlantis,—and that extensive land areas, though probably no actual connection, existed between South Africa on the west and the Indian peninsula on the east—the remains of Gondwana-land. To the same series of events which brought about the final collapse and submergence of those portions of the earth's crust may perhaps be attributed the great recession of the sea at the close of Cretaceous times, which was followed by mountain-building movements on a large scale, in some respects the most powerful and most extensive that have affected the earth's crust since the beginning of sedimentation.

CLIMATIC CONDITIONS IN THE MESOZOIC.—In the physical geography of a given period climatic conditions play an important part. It is a matter of difficulty to indicate them with certainty for comparatively recent epochs, but the difficulties increase rapidly with the remoteness of the period. The evidence relied on is necessarily of an indirect nature, and is usually based on a comparison of the distribution of the forms of life in the past with that of allied living organisms.

It has been claimed that the Jurassic fauna points to the existence of four distinct climatic zones somewhat similar to those of the present day and running nearly parallel to them. The equatorial zone coincided approximately with the Central Sea, the north and south temperate zones lying respectively to the north and south of it, while a boreal zone included the region around the North Pole, extending as far as the northern extremities of Europe, Asia, and America. The corresponding austral zone, if it existed, should be around the South Pole, but too little is known of those lands to draw any conclusions in regard to them. It is a striking fact that the fauna of the supposed south temperate zone differed widely from that of the equatorial belt, but presented strong affinities to that of the north temperate zone; while the absence of reef-building corals in the boreal regions, and their abundance in more southerly latitudes, afford additional evidence that the distribution of the organisms was dependent on temperature, for at the present day reef-corals require for their prosperity the high temperature of tropical or subtropical seas.

VOLCANIC ACTIVITY.—In India eruptions on an extensive scale took place during the uppermost Cretaceous. The Deccan traps are flows of

basic rocks which were poured out over the surface of the land probably from numerous fissures. They reach the enormous thickness of nearly 6000 ft., and are estimated to cover an area of about 200,000 sq. miles. The thick flows of basic rocks among the Karoo sandstones of South Africa are probably of Jurassic age, while eruptions of great magnitude characterize the later stage of the Cretaceous in western North America. In all those regions considerable displacements of the earth's crust took place towards the middle or at the close of the Secondary period, and it is not improbable that the manifestations of volcanic activity were connected directly or indirectly with the movements.

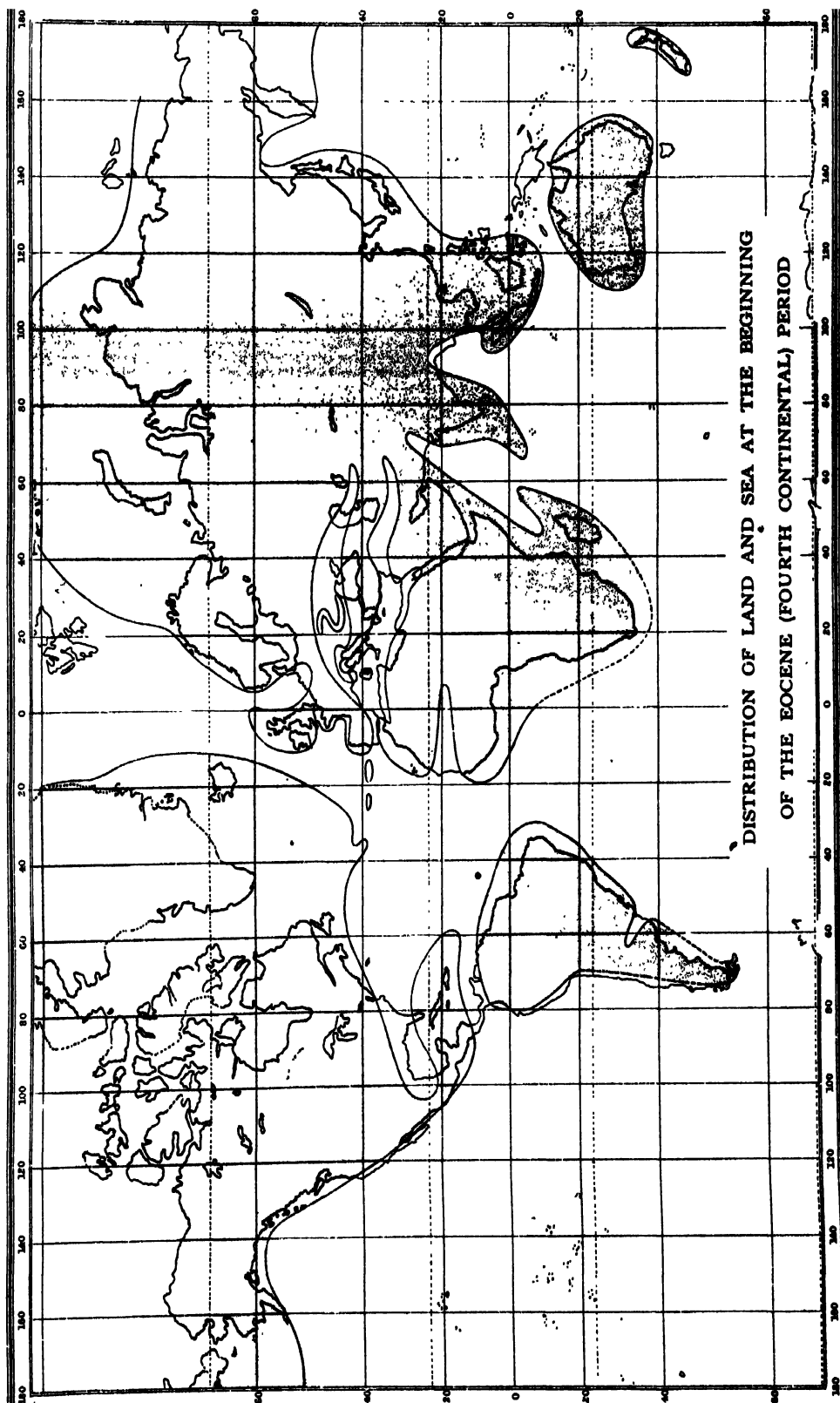
CHAPTER X

FOURTH CONTINENTAL PERIOD (TERTIARY)— EARTH MOVEMENTS, DEPOSITS

EARTH MOVEMENTS

CLOSE OF THIRD MARINE PERIOD.—We have now reached the closing stage of the great third marine period, when the margins of the extensive oceans began to recede, laying bare new land areas, and the deep waters were replaced by shallow seas. Enormous changes in the physical geography took place in a comparatively short time, geologically speaking. The contraction of the seas began to make itself felt before the last of the chalk had been deposited, while over wide areas the upper beds of the chalk were uplifted and exposed to denudation before the Tertiary period. That movement, together with minor ones which followed it, were, however, only the precursors of the more powerful and widespread disturbances of the earth's crust in Middle Tertiary (Miocene) times, which brought into being the most important features of the surface of the globe as we know it at the present day—the surface model, as it were, on which subsequent events have only effected modifications in details (see plate). In order more clearly to follow those changes, it will be convenient to consider their effects on certain pre-existing features, one of the most striking of which was the Central Sea.

SHRINKING OF CENTRAL SEA.—With the general recession of that sea new land appeared around its margin, while ranges of mountains began to rise within its boundaries, thereby greatly reducing its extent.



The importance of this period will be realized on comparing this with Plate F. (After de Lapparent.)

FOURTH CONTINENTAL PERIOD

The modern Mediterranean, the Caribbean Sea, and the small isolated or nearly-isolated basins of the Aral, the Caspian, and the Black Sea are all that remain of that great Central Ocean of the Secondary period. It is probable, however, that portions of the Atlantic came into existence as the result of extensive subsidence of land which once bordered that ocean. The region to the north of the Central Sea received an elevation *en masse* as well as a tilt to the north or north-west, whereby much new land appeared in central Europe, Asia, and North America, but regions nearer the pole were submerged. The mountain-building movement gradually died away to the northwards, but its effects are seen in the south of England.

EVOLUTION OF MEDITERRANEAN.—The evolution of the modern Mediterranean basin from the Mesozoic Central Sea is intimately connected with the birth and growth of the Alpine chain from the Apennines in Italy to the Carpathians and Caucasus. It will be remembered that during its greatest extension that sea occupied southern Europe, and southern and central Asia as far as the Pacific Ocean, but that subsequently its dimensions were much reduced; the connection with India was cut off, while the crests of the Apennines, Alps, and Carpathians appeared as islands within it. At that stage it reached on the east to the north of Persia and the source of the Euphrates; on the west there was a communication with the Atlantic Ocean across Morocco and the south of Spain.

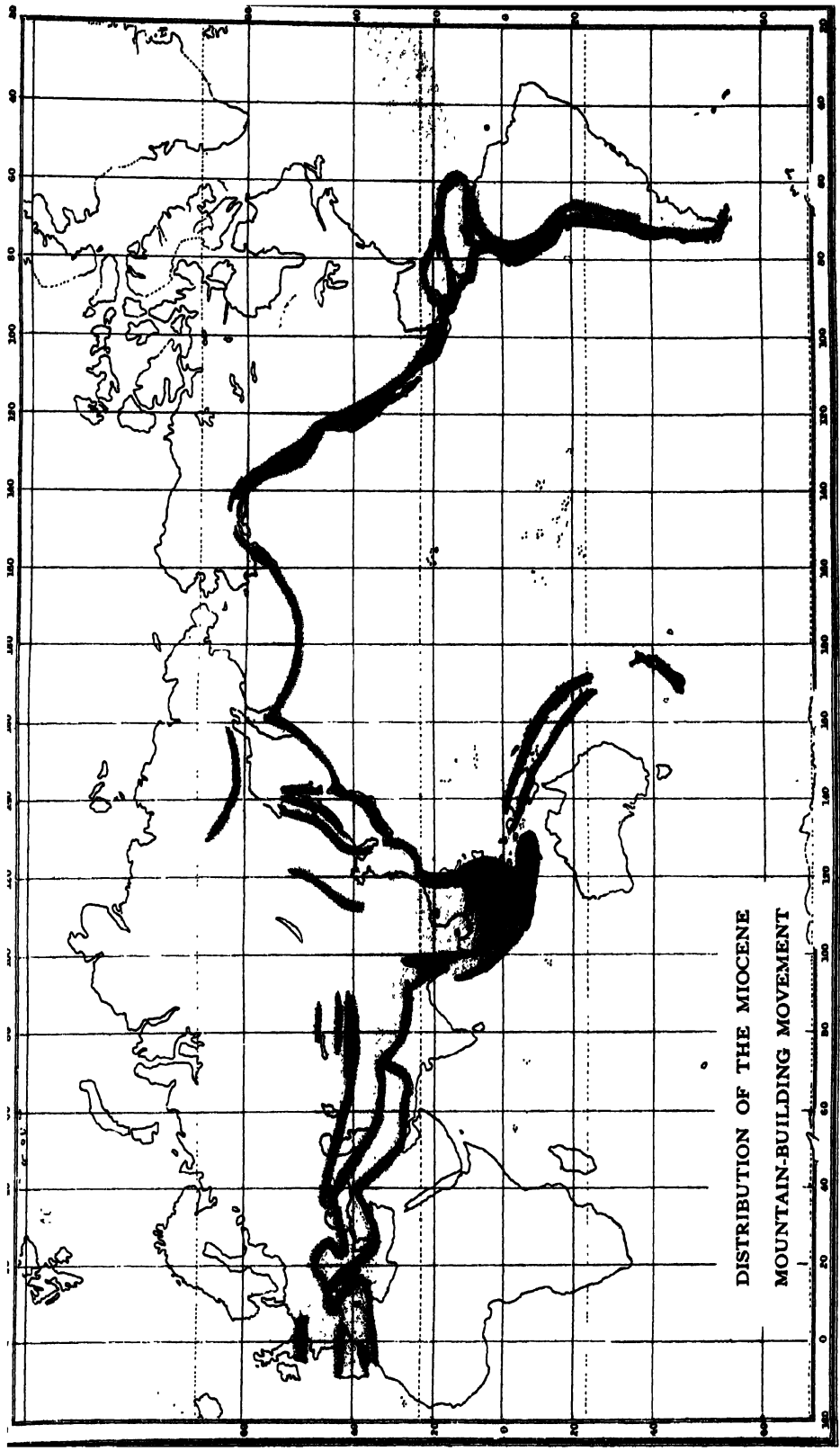
A period of elevation then followed, when the deposits previously formed round the margins of the embryo Alpine chain were uplifted and folded, and, in consequence, exposed to denudation. During the succeeding quiescent stage the sea encroached on its margins, due in part to the large quantity of sediment carried in from the new-formed land which was undergoing destruction, and in part to slow subsidence. The lower Rhone valley was occupied by an arm of the sea which penetrated along the northern margin of the Alps and Carpathians, and spread far over the south Russian plain to the Caspian and Aral basins, at the same time covering a large part of Austria-Hungary. The eastern limits were sensibly the same as in the previous stage, but the only communication with the Atlantic was along the Guadalquivir valley in the south of Spain. In the narrow northern arm, severed, as it was, almost completely from the larger southern body of water, rapid evaporation caused the precipitation of rock salt, which is now extensively worked near Cracow and in Transylvania, while reservoirs of petroleum and beds of mineral wax (ozokerite) are contained among the tenacious clays.

That stage was brought to a close by a great recession, when the whole valley of the Danube, the south of Russia, and the Aralo-Caspian area were lost to the Mediterranean, which was confined to a small tract lying wholly to the west of Sardinia and Corsica, and the deposits of the previous stage in the Rhone valley and Hungary suffered vigorous erosion. This is therefore the most important episode in the complicated history of that interesting region, and appears to coincide with the greatest period of elevation of the Alpine chain. Subsequent changes were in the direction of a general subsidence of the whole region, while local depression gave rise to the Adriatic and Ægean seas, and established a connection once more with the Black Sea, which had been temporarily lost.

Thus by a succession of uplifts and subsidences the Mediterranean was evolved from the great Central Sea, which had been in existence since the Triassic period. Each uplift added to the importance of the Alpine range, the formation of which was the proximate cause of the unrest in the region; while at each step the boundary of the range pressed towards the low plain or sea-covered area which lay to the north, clearly indicating that the forces which elevated the mighty chain acted upwards from the centre of the earth as well as horizontally in a general northerly direction.

The events which took place on the south side of the Himalayas have already been referred to on p. 105 *et seq.* There it was shown that the margin of the chain advanced *southwards* by degrees, and encroached on the tract now occupied by the Indo-Gangetic plain; the movement, though in opposite directions in the two chains, was otherwise very similar. The magnitude of the final upheaval may be realized from the fact that marine fossils of early Tertiary (Eocene) date have been found at elevations of 10,000 ft. in the Alps, 16,000 ft. in the Himalayas, and more than 20,000 ft. in Tibet.

CARIBBEAN REGION.—The history of the Mediterranean region in Middle Tertiary times was repeated on the opposite side of the Atlantic at the western extremity of the Central Sea. The Caribbean region of to-day is closely analogous in its geological history with the Mediterranean, for it has suffered episodes of mountain-forming movement and recession and advance of the sea, in the same manner and at approximately the same times. The chain of the Antilles, and another across the north of Venezuela, correspond to the Alps and Apennines, and the Gulf of Mexico, which lies in front of the folded range, to the low tract bordering the Alpine chain on the north. The difference between the regions lies only in the



DISTRIBUTION OF THE MIOCENE MOUNTAIN-BUILDING MOVEMENT

The shaded area indicates the chief regions affected. The deeper shading shows where the movement was most intense. Axes of special uplift shown by thick lines. (Mainly after Suess.) Note the festoon-like character of many of the chains, especially those around the Pacific Ocean.

actual elevation which the two have suffered. The Alps and Carpathians form a continuous belt, while the Antillean chain is interrupted, and exists only as a series of islands. A greater uplift of the region would unite the scattered islands and raise the Gulf of Mexico above the level of the sea, when the correspondence with the south of Europe would be complete. The resemblance between the two regions is not, however, mere analogy, for it goes farther. The chalk deposits of the Caribbean region are identical in physical character and in organic remains with those of far-distant southern Europe, while they differ widely from those of closely adjoining districts along the Pacific border—a condition of affairs which was maintained throughout various stages of the Tertiary

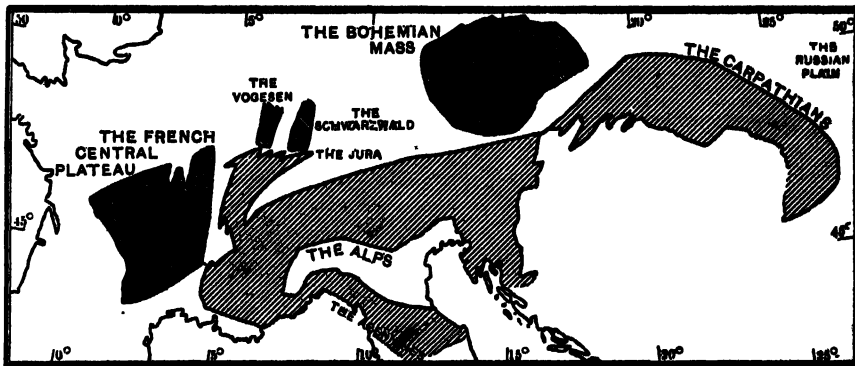


Fig. 39.—Sketch Map of the Alpine Chain and the Jura Mountains, showing their relation to the rigid Armorican masses lying in front of them

period. Further remarkable similarities will appear when we consider the distribution of volcanic activity and earthquakes on the surface of the earth.

COURSE OF ALPINE UPLIFT.—That the Alpine uplift pursues an extremely complicated course across southern Europe will be seen from a glance at the accompanying plate. Used in its widest sense, the following ranges must be understood as comprised within the term: the Pyrenees, dividing France from Spain; the Cordilleras, in the south of Spain; the Atlas and Algerian mountains, which range across North Africa; the Apennines; the Italian, French, and Swiss Alps; the Carpathians; the Balkans; and the Caucasus; together with several minor ranges which bound the Adriatic Sea on the north-east, and extend through Crete and Cyprus into Armenia.

The northern chain may be divided into two parts convex toward central Europe, viz. the Alps and the Carpathians, separated by a marked concave portion at their junction (fig. 39). These peculiarities throu

is interesting light on the history of the uplift, for they are found to stand in intimate relation to the geological constitution of the region in front of the chain. To the north of the great bulge of the Carpathians lies the vast Russian plain—a tract characterized by great simplicity of structure, inasmuch as it has escaped all the great earth movements which have at various times affected other portions of the crust, and the sedimentary rocks have therefore not been disturbed and rendered rigid to the same extent. As the Carpathians continued to grow in height, their margins pressed towards the low-lying region, and as no rigid obstacle impeded their advance they swept forward in that direction, involving more and more of the plain in their progress, until the forces of uplift were expended and the movement ceased.

BOHEMIAN MASS.—Now directly in front of the concave portion, between the Carpathians and the Alps, lies what may be called the Bohemian mass, the complicated geological history of which is reflected in the variety and rigidity of its rocks. It is, in fact, one of the stumps of the great Armorican chain which occupied central Europe at the close of Carboniferous times. Its rigidity acted as an effective obstacle to the forward movement of the Alpine margin in that direction.

CONFORMATION OF JURA MOUNTAINS.—To the west of the Bohemian mass lie other relics of the Armorican mountains. Their influence on the growth of the Alpine range is nowhere more clearly shown than in the folded Jura Mountains, which lie to the north—forerunners, as it were—of the main chain. Their front margin is curved or bulged towards the north, *i.e.* in the direction of movement of the main chain, as if the central portions moved freely forward while the ends were held back. The reason for this curious arrangement is not far to seek. On the east lie fragments of the rigid Armorican chain now represented at the surface by the Vosges and the Schwarzwald, but which are probably connected at no great depth with one another as well as with the larger Bohemian mass. On the west is the Central Plateau of France, a region which has much the same history as the other masses. Between them lies the Jura region, with a very different history. When the Armorican chain had there sunk to great depths, and been covered over by a great thickness of sediment prior to the date of the Alpine movement, the forces of upheaval picked out, as it were, the weak spot in the rigid barrier opposing the advance of the chain, and the movement spread in that direction, reaching farthest at the centre, while the margins were jammed against the rigid masses on each side. A similar state of affairs may be observed at the western end of the Alps, where the margin of

FOURTH CONTINENTAL PERIOD

that chain, freed from the influence of the Central Pyrenees suddenly bulges forward in a pronounced convex curve.

It appears, therefore, that the forces which elevated the Carpathians were directed from the south, which caused those chains to override the region lying to the north, except where rigid barriers imposed restrictions on the movement; but this rule does not hold good for the whole of the Alpine uplift, for in the formation of the Pyrenees and the north African range the folding forces were directed towards the south. On the east the Alpine chain is connected with the Asiatic uplift, wherein the elevatory forces were directed also from north to south. The transition from this direction to that obtaining along the north of the Carpathians seems to take place in the Caucasus range, which exhibits extremely complicated structures, resulting apparently from torsion or twisting of the strata.

ASIATIC UPLIFT.—The southern margin of the Asiatic uplift extends in a general easterly direction in gigantic curves convex towards the south, which on a map suggest a series of festoons (see plate). The most westerly of these is a short one, which runs across Asiatic Turkey to the confines of Persia; there it meets at an angle another range, which runs through Persia along the north side of the Gulf, and after skirting the Arabian Sea turns abruptly northwards parallel to the River Indus, which it follows as far as the Peshawur district. Along the line of that valley it joins the Himalayan range at a very acute angle. The south margin of the Himalayas exhibits the festoon-like curve in a striking manner; on the east, where the chain is breached by the Brahmaputra, it is met by the Burman and Malay ranges, which no longer preserve the easterly trend of the others, but for a great part of their course follow a meridional or north-and-south direction. They are, moreover, less clearly defined in their course among the scattered islands on the borders of the Pacific and Indian Oceans.

An explanation of this peculiar alternation of sweeping curves convex towards the south, with sharp re-entrant angles or bays, is suggested by the structure and mode of growth of the ranges. It is found that their southern margins have everywhere encroached on the region which lies to the south, viz. the Persian Gulf, the Arabian Sea, continental India, and the Bay of Bengal; and as the movement proceeded not from one but from several centres, it follows that several chains were in process of formation at the same time, all having the same tendency to encroach on the forelying region. This resulted in what may be crudely described as jamming—in other words, the separate chains at

portions, removed from the jamming influence, swept forwards until the chains assumed their present peculiar form.

It is a striking coincidence that both the Indus and the Brahmaputra, which originate to the north of the main Himalayan range, after skirting the chain for hundreds of miles in their attempt to force a passage, finally succeed each at opposite ends, where the progress of the elevation was checked. There are strong reasons for believing that those rivers were in existence before the uplift began, and that they flowed in a southward direction. The elevation of the chain across their course forced them into a new channel parallel to the uplift, and as the growth at the ends of the chain was probably slower than in the middle, the sea persisted there for a longer period. The barred rivers therefore found an outlet into the sea at those places, and moreover, they succeeded in maintaining their channels open by corrasion during the succeeding stages of the elevation.

The interior of Asia seems to have suffered elevation *en masse* to form the Tibetan plateau and the great desert areas, as well as special uplift along certain lines, of which the Hindu Kush, the Kuen Lun, and Tian Shan mountain ranges are the most important results. On the east the movements blend with those which took place at about the same time along the Pacific margin.

PACIFIC BORDER.—In an earlier chapter it was stated that in the Secondary period nearly the whole margin of the modern Pacific Ocean was under the sea. The change to present conditions occurred during that great phase of earth movement of middle Tertiary times, when the sea floor was elevated to form gigantic ranges like the Andes of South America, and in great part the Rocky Mountain and coastal chains of North America. As a result of the elevation the Pacific became ringed by an almost complete girdle of mountain ranges (see plate), many of which exhibit the festoon-like arrangement characteristic of the Asiatic chains. The Aleutian Islands, Kamchatka and the Kuriles, Japan, the Philippines, and New Zealand may be noted as striking examples.

NORTH FRANCE AND SOUTH ENGLAND.—Little need be said of the effects of the Alpine movement in central Europe, as only feeble indications of it have been observed there. The Tertiary beds of the Paris Basin are traversed by axes of uplift, which are, however, of little consequence. Two of these penetrating into the south of England gave rise to the Wealden arch, which has been previously referred to; a third,

to the north, indicating that the pressure came from the south. The Isle of Wight is traversed from end to end by a belt of vertically turned strata, which represents a part of the steep limb of the fold. The outline of the island is due to the vertical ridge of chalk, which is bounded on each side by softer strata. The chalk has resisted the ravages of the weather and the waves, and stands out boldly at each end, while the adjacent beds have been denuded away, the wear being greater as the distance from the protecting chalk ridge increases, thus giving rise to the lozenge shape characteristic of the island.

As has been explained in a previous chapter, the Weald drainage system is a direct consequence of the Tertiary elevation. This intimate connection between the drainage and the folding of the strata is noticeable in the south of England wherever the effects of the movement made themselves felt. The watersheds follow the more important axes of uplift, and the main streams flow into the synclinal troughs on each side.

This leads one to enquire how far this relation holds in other regions where that movement was felt.

The intricate DRAINAGE SYSTEM OF EUROPE is the result of the many complicated changes which have at various times affected the region. Many of the main lines must have been in existence before the Alpine movement began to operate, and therefore the chief rivers flowed into the important marine areas of Cretaceous and early Tertiary times; when new land arose in and around those seas as a result of the later movements, new systems of drainage were started, and many of those already in existence were modified. It will be noticed on any map that the main watershed of central and eastern Europe follows a course approximately parallel to and at some distance to the north of the Alpine chain as far as the Carpathians, whence it swings in a north-easterly direction across Russia to the Ural Mountains. The most important rivers flow into one of three areas: the Arctic Ocean, the Baltic-North-Sea region, and the Mediterranean basin, including the Black Sea and the Caspian.

It will be observed also that the greatest number of rivers, and by far the most important, flow into the latter basin, where, it will be remembered, an important ocean had existed from the beginning of the Secondary period, if not prior to that. In the Baltic-North-Sea area the chalk and Tertiary deposits of France, North Germany, and England

were laid down; while there is evidence that the part of the Arctic Ocean which receives the remainder of the drainage was submerged at the close of the Cretaceous period.

It is probable that the main watersheds were determined by unequal emergence or slight tilting of the sea floor during the general elevation of Europe which slightly preceded the mountain-building movements. The reason why the Danube crosses the chain in two places may therefore be that it flowed towards the south before the elevation began, and that it kept its course open in spite of it. Smaller rivers, and even the tributaries of the larger ones, show a close connection with the directions of the axes of uplift, as, for example, the upper Rhone and the tributaries of the Saone in the Jura Mountains; while the Italian rivers are strictly consequent on the uplift of the western Alps and the Apennines.

DRAINAGE SYSTEM OF NORTH AMERICA.—In North America the convergence of the lines of drainage towards the region last vacated by the sea in Tertiary times is remarkable, for the rivers draining nearly a third of the continent pour their waters into the Gulf of Mexico, which is to North America what the Mediterranean basin is to Europe. In the western territories, and along the Californian coast, the positions and directions of the divides and watercourses have been determined by the middle Tertiary movements.

DRAINAGE SYSTEM OF SOUTH AMERICA.—In South America, as the eastern slopes emerged slowly from under the Cretaceous and Tertiary seas the rivers increased in length as the elevation proceeded; while the Tertiary movements, which elevated the whole Andean chain at the same time fixed the main watershed of the country close to the Pacific border. The result is seen in the strangely unsymmetrical distribution of the drainage, of which the Pacific Ocean only receives a minute fraction, while the Atlantic monopolizes the rest.

MOUNTAIN BUILDING.—Mountain ranges such as the Alps, the Andes, or the Himalayas, have been shown to be the result of great compression in the crust of the earth, whereby the strata which occupied a certain area were crowded into a smaller space by violent buckling. Mention has been made of movements of another type which have at various times affected parts of the earth's surface, and are due to tension in the crust, which causes the strata to tear apart, and large areas are depressed relatively to their surroundings. It can be proved that by so doing the strata occupy more space after the movement than before, and thus the tension is relieved. Chains of mountains do not arise from displacements of this kind; the cracks or faults along which the strata

give way tend to form an irregular network, somewhat like those which develop in drying mud, and the surface is broken up into many-sided blocks, often of great size, which are depressed and tilted to varying amounts. A fair idea of the effect of such a movement can be got by observing the way in which a sheet of ice breaks up when the water which supports it is removed. Displacements of this kind often attend the later phases of mountain-building; the elevatory forces appear, as it were, to overreach themselves, and to set up a tension in the crust, which must be relieved by normal faulting; but they occur also independently of movements of compression, for during the Tertiary period large tracts of land in the north Atlantic region suffered subsidence, and it is probable, indeed, that that part of the ocean came into existence in this way.

DEPRESSION BY FAULTING.—The Alpine elevation was followed by extensive depression, whereby parts of the Mediterranean basin were deepened and its margins were extended; the Adriatic Sea came into existence as the result of a series of step faults lowering the central portions relatively to its borders. In Transylvania the subsidence, although great, was not sufficient to reduce that area below the level of the sea.

Similar depressions followed the folding of the western territories of North America. The Great Basin and Salt Lake regions are traversed by powerful faults, which have broken up the surface into enormous blocks tilted in various directions. As denudation in these arid regions is not so rapid as in temperate climes, the course of the displacements are still marked by lines of cliffs which bring the structure of the area and the nature of the movements vividly before the observer. In some cases the faults are accompanied by flexures, produced by the dragging down of the edges of a stationary block by the surrounding depressed portions.

The broken nature of the girdle of mountain chains surrounding the Pacific in its course through eastern Asia and Malaysia has been attributed to subsidences following the elevation of the chains.

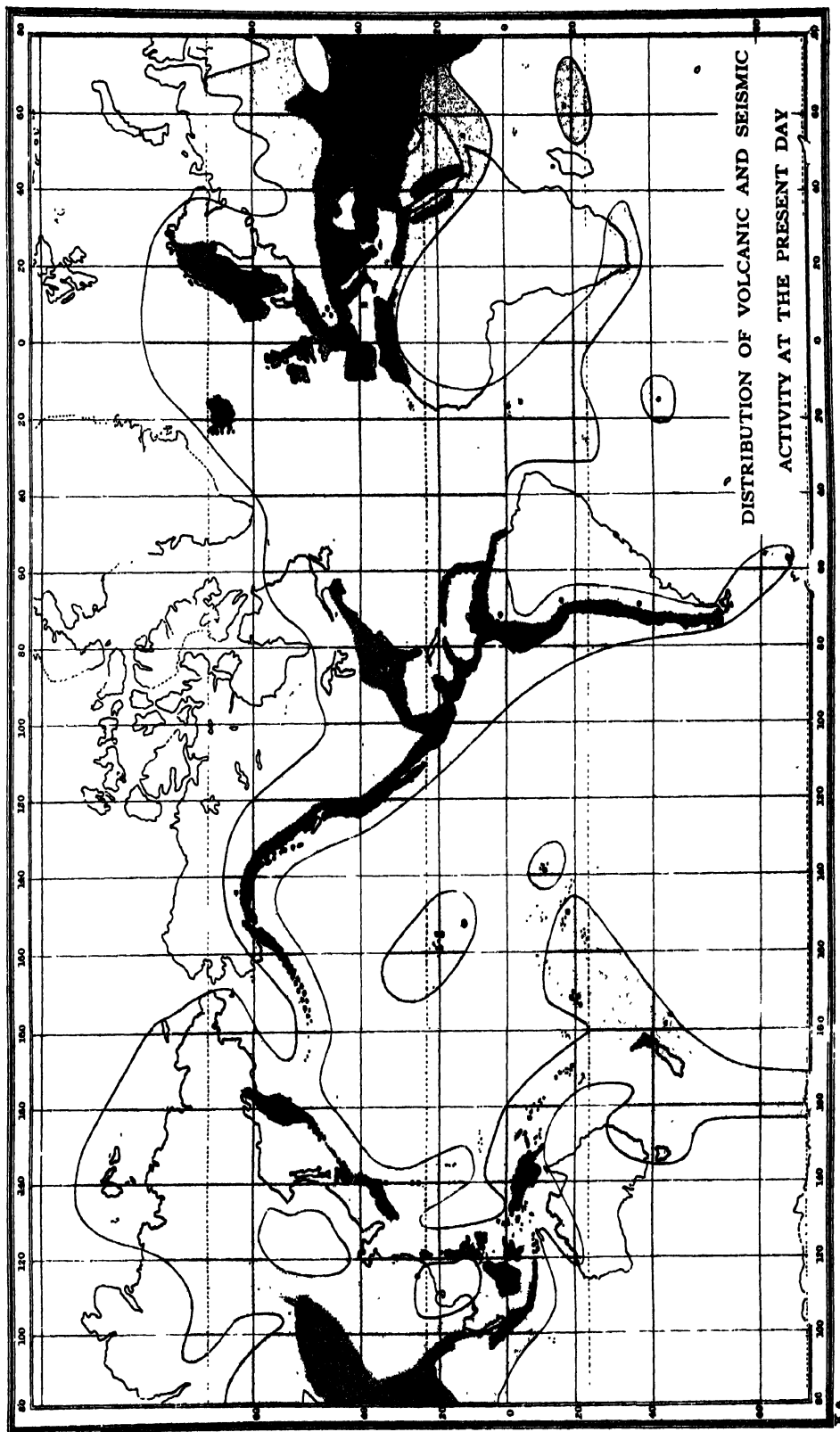
VOLCANIC ACTIVITY.—It will be remembered that the disturbances of the earth's crust which caused the second and third continental periods were accompanied or followed by volcanic activity. The fourth and latest movement offers no exception, for the course of the elevation is everywhere marked by lines of volcanoes, many of which have been long extinct, and their great conical accumulations are being denuded away, but others are still active, and continually adding to their height by fresh outpourings of lava, ash, or volcanic mud. On referring to the accompanying plate it will

be seen that, with very few exceptions, all the most important volcanic centres at the present day are confined to two well-marked belts—the first surrounding the Pacific Ocean with an almost complete girdle, while the second extends nearly halfway round the earth from central America to the Malay Archipelago, and meets at both ends the Pacific girdle.

It is useless to mention the individual cones which are still active, for their number is very great, but attention may be called to the fact that their distribution coincides everywhere with the region affected by the Tertiary mountain-building movements. They are specially prone to occur in those tracts which have suffered subsequent depression by normal faulting. This seems but natural, for the pent-up magma reaches the surface by the easiest passages, and these must occur more frequently in those regions which have been recently fissured and displaced than in relatively stable areas. It has been supposed, too, that reservoirs of molten rock must be produced by movements of elevation; for it is claimed that the intense pressures which normally prevail at a depth suffice to keep the materials in a solid or pasty state in spite of the temperature, but that when the pressure is relieved, by the formation of mountains the pasty material becomes fluid, and forces a passage upwards along lines of weakness. This view is coloured too much by notions of the possible constitution of the interior of the earth—about which so little is known—to be regarded as more than a suggestion.

It will be seen from the map that some important volcanic areas lie outside the two belts already described. One of these—Iceland—lies in the north Atlantic; others are in the south Atlantic, between Africa and South America; and another in the Indian Ocean near Madagascar; while others occupy some of the islands in the centre of the Pacific. With regard to those in the Atlantic and Indian Oceans, it may be mentioned that both those regions have probably increased in size comparatively recently by extensive subsiding movements, and the connection which appears to exist between the distribution of volcanic activity and earth movements may therefore still hold good in those cases.

In addition to cone accumulations, there were eruptions of basic lavas which gave rise to an extensive plateau. Remnants of it are now found in the north-east of Ireland and on some of the western isles of Scotland, and probably also on Iceland and Greenland. The eruptions seem to have been from numerous fissures following faults or other planes of weakness, for the region around the present margin of the plateau is traversed by innumerable dykes of basic rock such as might have fed the eruptions, and it is only natural to conclude that similar



The shaded portions indicate the areas where earthquakes are felt. The darker shading shows the regions where shocks are severe and frequent. Volcanoes are shown by dots. (From W. & A. K. Johnston's *Atlas of Physical Geography*.) Comparison with Plate H will show the close connection between seismic and volcanic activity at the present day and the Miocene movements.

dykes exist concealed beneath the flows. How far the plateau extended it is impossible to tell. It is probable that some part of Atlantis still persisted in the north Atlantic during the period of eruption. The scattered remnants of the plateau now preserved have escaped denudation by faulting, which, however, was not sufficient to submerge them.

TERTIARY DEPOSITS

PLIOCENE.—The Miocene elevation shifted the areas of sedimentation into the modern seas, and therefore subsequent marine deposits are scanty and of scattered occurrence on the present land. Such deposits as are accessible are mainly found bordering the great mountain ranges, and have been exposed as a result of the continuance of the uplift which raised the mountains. Marine Pliocene strata are known from various districts in Italy; they are of shallow-water types, indicating a close proximity to a shore line, and their later stages pass up into fluvatile deposits resembling the Pliocene of other areas in Europe and elsewhere; also in south-eastern Europe, where they point to formation in an inland sea. Around the northern border of the Alps and various isolated areas in central Europe sands and gravels of fluvatile origin containing bones of mammals are the usual representatives of the Pliocene epoch, but the deposits of the south-east of Europe appear to have been formed in inland seas, and contain a mixture of marine and freshwater shells.

In the east of England and Belgium there are estuarine and river deposits alternating with others which are probably marine. They are of Pliocene age, and are considered by some to have been formed along the estuary of a large river forming the continuation of the modern Rhine, to which the Thames and various east-coast streams would be tributaries. Their chief interest lies in the evidence they afford of a gradual lowering of temperature during the period. The remains of plants and other organisms indicate that the earlier Pliocene beds were deposited under warmer climatic conditions than those of the present day, but the temperature seems to have fallen gradually, and in the later sediments occur the remains of plants and animals which now live in the extreme north of Europe. There is therefore an evident preparation for the climatic conditions which followed immediately on their deposition. A possible much greater extension of Pliocene deposits is indicated by isolated patches in the south-west of England and by the occurrence of Pliocene fossils in the glacial beds of Scotland, the latter having been derived, it is supposed, from deposits concealed under the sea.

In North America the chief area of sedimentation lay around the Gulf of Mexico and the Atlantic coast to the north. Isolated patches occur also in the southern and western States and along the Californian coast. In some parts of these regions they are said to occur at a height of 4000 ft. above sea level. The Pliocene deposits near San Francisco are claimed to have a thickness of 13,000 ft., which, if true, is far in excess of anything known elsewhere.

It appears from the altitudes at which Pliocene sediments are now found that the Miocene elevation had not expended its force until the succeeding epoch. This was specially the case in western North America, where great folding and faulting movements appear to have been in progress throughout. As the Siwalik deposits fringing the Himalayas are in part at least of Pliocene age the same conclusion seems to be justified for that region (see p. 107). After the close of the Pliocene the surface of the land and the relative distribution of land and sea did not seriously differ from their present aspect.

[Article on Geology continued in next volume.]

